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ORGANIZATION OF THE LICK OBSERVATORY.

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Committee of the Regents on the Lick Observatory,

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PART I.

SELENOGRAPHICAL STUDIES,

BASED ON

NEGATIVES OF THE MOON TAKEN AT THE LICK OBSERVATORY,

BY

PROFESSOR LADISLAS WEINEK, PH.D., SC.D.,
Director of the Imperial and Royal Observatory of Prague,

WITH AN INTRODUCTION

BY

PROFESSOR EDWARD S. HOLDEN, M.A., LL.D.,
Director of the Lick Observatory.

The plates of the Moon which are reproduced in this volume are a gift to Science from

WALTER W. LAW.

PART I.

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INTRODUCTION.

BY EDWARD S. HOLDEN.

On June 1st, 1888, the Lick Observatory was transferred by the Lick Trustees to the Regents of the University of California, and the scientific history of the establishment begins with that date. In a future volume of these *Publications* it is intended to print a description of the objectives and mounting of the great equatorial, and the investigations which have been made of the various constants of the lenses.*

For the present, it will be sufficient to say that besides the visual objective of 36 inches aperture and 694 inches focus, the Observatory possesses a photographic corrector, or third lens (a *meniscus* of crown glass), of 33 inches aperture, made by Mr. ALVAN G. CLARK. When this lens is placed in front of the visual objective, it forms a photographic combination having a focal length for stars of about 570.2 English inches. $f \div a = 17 \pm$. $1'' = 0.00276$ inches; $1' = 0.1658$ inches; $1^\circ = 9.948$ inches.

The radii of curvature of the visual objective (as measured by Mr. GEORGE B. CLARK) are:

$R^1 = +259.52$ inches, $R^3 = -239.59$ inches,
$R^2 = +259.52$ inches, $R^4 = -40000.$ inches.

The corresponding radii of the third lens, or photographic corrector (as measured by Dr. HENRY CREW), are:

$R^5 = +255.15$ inches, $R^6 = -302.12$ inches.

The crown glass of the visual objective was made by M. FEIL, and is numbered 1734; the flint glass is FEIL, No. 1588; the crown glass of the third lens is FEIL, No. 1937. From the elaborate investigation of the constants of the prisms of these three glasses, made by Professor C. S. HASTINGS, of Yale University, in the years 1887 and 1889, which is printed in Part II of this volume, I extract the following tables and formulæ.

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* Reference may be made, in passing, to various notes in the *Publications of the Astronomical Society of the Pacific*, vol. I, p. 123; vol. II, p. 25; vol. II, p. 160; vol. II, p. 258; vol. III, p. 141; vol. III, p. 244; vol. IV, facing p. 51; vol. IV, p. 183; vol. V, p. 179; vol. V, p. 219, and especially to an investigation of the optical constants of the glass by Professor C. S. HASTINGS, printed in Part II of this volume. *See also* a paper by Mr. H. D. TAYLOR in *Mon. Not.* R. A. S., vol. 54, p. 67.

The changes in *n* (index of refraction), due to temperature (T) centigrade for these prisms, may be calculated from the formulæ:

$$\begin{array}{lll} (1734) & \frac{\Delta n}{\Delta T} = & -1.88 + 0.286 \frac{1}{\lambda^2}, \\ (1588) & \phantom{\frac{\Delta n}{\Delta T}} = & +2.53 + 1.05 \frac{1}{\lambda^2}, \\ (1937) & \phantom{\frac{\Delta n}{\Delta T}} = & \text{Same as for 1734.} \end{array}$$

TABLE OF THE VALUES OF *n* AT BAROMETER = 30 INCHES, AND TEMPERATURE OF 20° C.

Line.	Crown No. 1734.	Flint No. 1588.*	Crown No. 1937.
A	1.508721 ± 1.3	1.618812 ± 0.8	1.508353
B	1.510606 2.2	1.622258 1.8	1.510284
C	1.511565 1.5	1.624043 0.8	1.511268
D^2	1.514164 1.1	1.628994 1.8	1.513934
0.5614	1.515474 0.6	1.631578 2.3	1.515280
E	1.517440 2.7	1.635476 1.8	1.517276
F	1.520316 2.2	1.641340 1.8	1.520233
G	1.525677 2.2	1.652674 1.0	1.525740
0.3956	1.530485 0.5	1.663358 0.7	1.530700

*The Flint lens of the 30-inch equatorial at Nice is made from this glass also.

The probable errors of *n* for 1937 are of the same order as those in the two other columns. They have not been separately determined.

The figure of the visual objective is practically perfect, and it is in perfect adjustment. The adjustment of the photographic corrector is best when its cell is screwed flat against the cell of the visual objective, as has been proved by experiments by Professor CAMPBELL and myself. The figure of the photographic corrector is not perfect, though it is very good.

The photographic corrector was figured partly at Cambridge, and partly at Mount Hamilton in the winter of 1887–8. This winter was very severe, and the temperature of the room in which the lens was corrected often could not be maintained above the freezing point of water. Much of the work was done when all the water used in polishing was full of ice particles, except that part immediately under the hands of the operator. During this period the water engines for moving the dome and floor were not in working order, and the opening of the dome could not be moved to different parts of the sky, nor could different stars at widely different altitudes be employed as tests. Thus the circumstances were most unfavorable. Test photographs of stars out of focus show that the diluted disc of a bright star is not entirely round, and that the light is not spread uniformly over it, as it should be. The center of the objective is too short in focus, and a prominent ring remains near the outer border. Professor E. C. PICKERING was kind enough to have similar tests made for us with the 11-inch telescope made by the CLARKS for Dr. HENRY DRAPER. These plates show an absolutely round image, and are entirely free from rings, and the light is uniformly distributed throughout the disc. The DRAPER objective is a test of the work of the CLARKS under ordinary conditions. The defects remaining in our own photographic corrector are almost entirely due to the extremely unfavorable circumstances under which the work at Mount Hamilton was done.

The very sharpest definition on the Moon is given by using an aperture of about 8 inches. This aperture has been chiefly employed up to the present time in making pictures of the Moon, partly on account of the good definition, and partly because the exposure times with 8 inches aperture were long enough to be given with the shutter which was the only one available until recently. It is intended to increase the aperture employed and thus to gain the great advantages which result from very short exposures, which may more than counterbalance the slight errors due to the imperfection of the figure of the objective. A shutter suitable for short exposures could not be constructed until the summer of 1893, for lack of funds and of skilled workmen.

The driving-clock runs almost perfectly with or without control. The gearing which connects the clock with the polar axis has, however, a periodic inequality with a period of 3 *m*.* (discovered by Professor SCHAEBERLE), which we have not yet been able to remove.

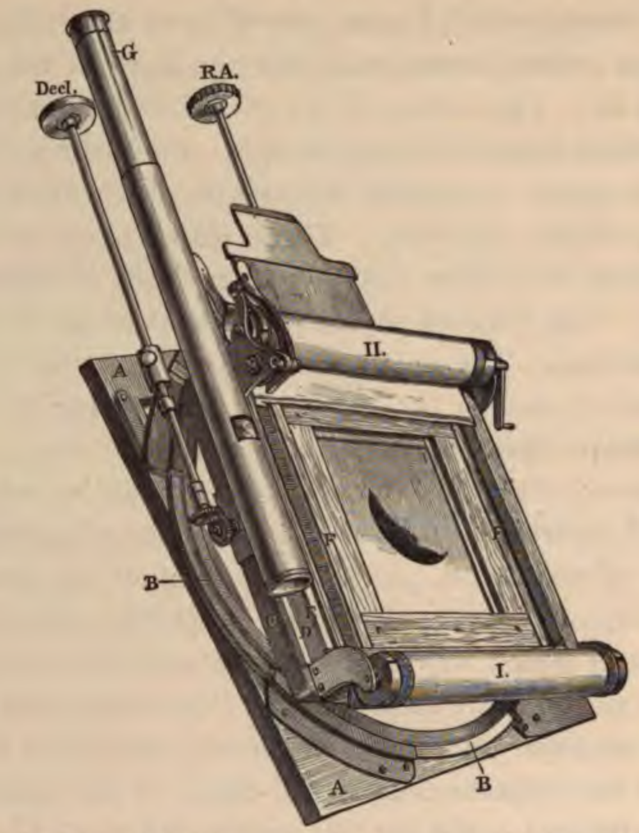
The sensitive plate is held, at the principal focus, in a compound slide-rest, of which a cut is inserted. The various enlarging lenses are likewise held here, by screwing them into wooden slides, which take the place of the ordinary plate-holder.† 8x10 plates are usually employed in the focus, though arrangements are made for using plates as large as 11x14 inches.

The frame A A is fixed in the tube at right angles to the optical axis. The frame D and everything above is movable in declination by the handle Decl.; the frame E and the eye-piece G are movable in right-ascension by the handle R.A. The guiding eye-piece G receives a beam from the object-glass, and the image of a star can be kept on its cross-wires by suitably moving the handles. The wires

---

* The difficulty of removing this inequality is due to the fact that the train contains several wheels whose period is 3 *m*. If there were but one, the matter could be adjusted very quickly. The practical lesson is that such trains should be designed so that no two wheels have the same period, so far as this is practicable.

† F F of the engraving.



COMPOUND SLIDE-REST FOR CARRYING THE NEGATIVE PLATE OF THE 36-INCH EQUATORIAL.
(The cut is printed by the courtesy of the Council of the Royal Astronomical Society.)
The mechanical parts were made by WARNER & SWASEY; the optical by J. A. BRASHEAR.

are lighted by a small incandescent lamp. The plate-holder F F shown in the cut is 8x10; the image of the Moon is about 5 inches in diameter. I and II are curtains on spring rollers, for quick exposures. The two handles and the end of G project several inches outside of the telescope-tube. The whole apparatus can be rotated in position-angle through 25° on the ring B B.

A port-hole, 12 inches by 23 inches, giving access to the photographic focus, was cut in the tube shortly after the telescope was received at the Lick Observatory, in 1887, in a place selected by the Lick Trustees. The selection was unfortunate. This hole is directly on top of the tube when the telescope is west of the pier and when it is pointed to an hour-angle 3½ hours east of the meridian and to a declination of 37° south. It should have been cut exactly opposite to that rectilinear element of the tube which runs through the foot of the declination axis of the telescope. The diameter of the telescope-tube at the port-hole is about 3½ feet. A little consideration will show how extremely and unnecessarily difficult certain photographic work is made by this arrangement.

In front of the sensitive plate are two shutters. The first of these, known as the "velvet shutter," is a square door on hinges, which covers the circular opening

(14 inches in diameter) in a diaphragm of the tube, which is 12 inches nearer the objective than the focal plane. It is moved by a handle on the outside of the tube. This shutter is convenient, though not essential. When it is closed, the slide of the plate-holder can be drawn and various manipulations can be made in safety. The second shutter is made of aluminium and consists of two rectangles of this metal, which close directly over the center line of the sensitive plate. These rectangles move in a plane parallel to the focal plane and 3 inches nearer to the objective. They open with the slightest pull and uncover the whole of an 8x10 plate. They are moved by cords, which extend to the outside of the tube of the telescope. The frame which holds the aluminium shutter can be rotated in position-angle and clamped in any position. This second shutter was not available until the summer of 1893. The curtain (I, II, of the preceding wood-cut) has been removed.

There are two enlarging lenses. One is an ordinary photographic camera lens (made by Mr. Alvan G. Clark), whose aperture is 2 inches and whose focus is about 14 inches. It is used in photographing the Sun; and when placed as we employ it, it magnifies about 8 diameters. This is found to be a direct enlargement too great for pictures (of *Jupiter*, for example) taken under our ordinary atmospheric conditions. The second enlarging lens was made by Mr. J. A. Brashear, from computations by Professor C. S. Hastings, of Yale University. It was purchased from a grant made to the Lick Observatory by the Trustees of the Elizabeth Thompson Science Fund of the A. A. A. S., to whom our grateful thanks are due. Its aperture is 2.1 inches, its focal length about 18.5 inches. Its constants are:

$$\left.\begin{array}{l} r^1 = +20.82 \text{ ins.} \\ r^2 = -4.891 \text{ ins.} \end{array}\right\} \text{Jena flint glass,} \quad \left.\begin{array}{l} r^3 = +4.891 \text{ ins.} \\ r^4 = +12.59 \text{ ins.} \end{array}\right\} \text{Jena crown glass.}$$

It magnifies approximately 5 diameters; and experience has shown us that this is about the amplification (of *Jupiter*, for example) which is best suited to our ordinary atmospheric conditions, though there are several nights in every year where an amplification of 10 diameters might be used to advantage.

These amplifying lenses, when in use, are placed farther from the objective than the focal-plane. The image is received on an 8x10 sensitive plate, which is held in a compound slide-rest of wood (movable in two directions, as R.A. and N.P.D.; and also movable in position-angle). The sensitive plate is placed very near to the principal focal-plane of the *visual* objective (10½ feet farther from the object-glass than the principal focus of the photographic combination), and it is movable to and from the objective by the regular focusing-screw, through a distance of about 6 inches. It will be obvious that the large size of the telescope, and other reasons, make the mechanical arrangements for photography somewhat inconvenient. The present devices are as simple as they can be made, however, and they work well. In contriving them I have had the very practical advice and assistance of Professor SCHAEBERLE. The focal-plane of the photographic telescope is, of course, different for light of different wave-lengths, and allowances (based on experiment) are made for the difference.

Part of the cost of the early experiments in photography with the 36-inch telescope, including the trial of different kinds of plates, has been met by several small appropriations of money by the Smithsonian Institution of Washington, through the kindness of the Director, Dr. S. P. LANGLEY, to whom our sincere thanks are offered. The timeliness of these grants of money was especially important, as it permitted our work to go on continuously without the serious interruptions which otherwise would have ensued.

Professor S. W. BURNHAM was placed in charge of the photographic work with the great telescope in July, 1888. During the month of August, 1888, he made a number of negatives of the Moon in focus, some of which were of great excellence and beauty.* No more Moon negatives were made during 1888 and 1889. In 1890 I took charge of the photographic observations with the 36-inch equatorial. Messrs. SCHAEBERLE and CAMPBELL assisted in the observations in the dome, and the negatives were developed by Messrs. BURNHAM, BARNARD and CAMPBELL, in the intervals of other work. It was not until the latter part of the year 1892 that the services of a regular assistant in photography were available at all; and it was not until March, 1893, less than a year ago, that Mr. COLTON could give his entire time to such work. Under the circumstances, I determined to devote the photographic telescope to the making of a series of negatives of the Moon, which should be so complete as to cover the whole history of a lunation, and should include photographs made at various critical stages of libration. Such a series is immediately valuable in giving a true plastic representation of the lunar surface; it becomes available for comparison with past photographs, such as those of Messrs. RUTHERFURD, DE LA RUE, ELLERY, DRAPER, PRITCHARD, HENRY, PICKERING; and with series to be obtained in the future. If the question of changes in the lunar surface is ever to be settled, it must be through comparisons of such photographs. Even the best drawings (unless they are based on photographs) are too uncertain and conventional for a purpose like this. Nothing is more certain than that changes must occur in the lunar topography. Gravity is constantly acting to tear down existing structures on the Moon as on the Earth.

Nothing is less satisfactory than the evidence for such changes based on drawings and maps alone, leaving out of account two or three instances. Lunar photographs, then, are of the first importance in their bearing upon questions of physical change in the Moon. Certain other problems can be studied upon negatives (or upon transparencies made from them) with great advantage; such as the nature of the bright radiating streaks, etc.; the courses of rill-systems; the profiles of individual craters or mountain ranges; the heights of lunar peaks and the depths of lunar depressions, etc.; the latitudes and longitudes of lunar landmarks; the constants of lunar librations, etc., and generally everything relating to the topography and geology of our satellite. The first results obtained here in lunar photography showed that admirable negatives could be made with the large telescope. My earliest examinations and comparisons of the negatives convinced me that they contained a wealth of detail quite unknown in previous work of the kind, and that they were admirably suited to provide the data for a new study of the Moon's topography. The very limited force at the Lick Observatory made it entirely impossible to undertake such studies here. I therefore entered into correspondence with Professor WEINEK, Director of the Observatory of Prague, and, during 1889, placed our negatives freely at his disposition. Professor WEINEK'S previous experience in lunar observations and in photography, as well as his very unusual artistic skill, made his advice and assistance of extreme value, and the Lick Observatory was so fortunate as to secure his hearty coöperation from the very first. We owe it to him that the results which can be obtained from our Moon negatives have been quickly made known.

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* For a list of these negatives, see the *Publications of the Astronomical Society of the Pacific*, vol. III (1891), page 63.

From the beginning of the year 1890, we have worked together toward one object—namely, to make the original negatives as good as possible, and to obtain from them the surest results. In doing this much had to be learned, and the present volume is a record of our experiments, and of some of our conclusions.

After the original negatives were secured, it was necessary to make many experiments to determine the best manner of obtaining enlargements from them. The plate of *Mare Crisium* (4-fold enlarged) exhibits the first success of Professor WEINEK in this direction. 34¾ hours of actual drawing are represented by this plate. The plates of *Archimedes* and *Arzachel* (10-fold enlarged) correspond to a marked advance. *Petavius* (20-fold enlarged), on which 120½ hours of actual drawing were expended, represents another distinct step forward. Finally, *Copernicus* (20-fold enlarged) seems to be as perfect a result as can be obtained by making drawings from the Lick Observatory negatives in their present state. This drawing represents the great labor of 224¾ hours, and is a monument of skill and patience, not to speak of its high scientific value.

While such experiments in making enlarged drawings from the negatives were going on, attempts were also made to enlarge the Moon's image directly in the telescope. These experiments were not particularly successful, for reasons which will be given later on. It was then attempted to enlarge the negatives made in the focal-plane by a subsequent exposure in the camera. The best result reached in this way up to June, 1892, is the plate of *Mare Crisium* in this volume (2-fold enlarged) made by Professor BURNHAM. In July, 1892, I secured the (temporary) services of a professional photographer, Mr. W. O. AMSDEN, to make copies and enlargements of our negatives for exhibition at the World's Fair in Chicago.*

A very few experiments showed that it was perfectly practicable to enlarge all the Mount Hamilton negatives of the Moon to a scale of III feet to the Moon's diameter with advantage. The first results of Mr. AMSDEN were as good as any which we have obtained at the Lick Observatory. The excellent plate of the lunar *Apennines* (7-fold enlarged) by Mr. COLTON, given in this volume, represents our III-foot enlargements very well.

It had long been my hope to make maps of the Moon from our negatives on two scales, namely: 1st. III feet to the Moon's diameter, the scale of MAEDLER'S and LOHRMANN'S maps; and 2d. VI feet to the diameter, the scale of SCHMIDT'S map. Whatever scale is chosen, it is necessary to make a complete map on this scale. Supplementary charts of special regions on a larger (or smaller) scale, and under special conditions of illumination, may well be added. But the whole Moon should be presented on one scale, and it is very desirable that each region should be shown under (at least) two different illuminations—under morning and evening Sun, or under high and low Sun, for example. As the photographic difficulties (not to speak of the expenses) increase rapidly with increased magnifying, it is advisable not to enlarge more than just enough to exhibit satisfactorily the features which it is desired to show. For very many purposes, an enlargement to the scale of MAEDLER'S map is sufficient. The successful experiments of 1892, corresponding to the plate of the *Apennines* in this volume, made it certain that an enlargement to this scale was entirely practicable. The plate of *Langrenus*, *Vendelinus*, *Petavius*, etc. (from the negative of August 31, 1890), and the plate of the lunar *Apennines*, are copied from enlargements in the camera by Mr. COLTON, of the Lick Observatory, to a scale of III feet to the diameter, and represent what sections of the proposed map would be like.

In the meantime our negatives had fallen into the hands of Baron ALBERT VON ROTHSCHILD, of Vienna, whose experiments upon them resulted in producing magnificent carbon enlargements of quite extensive areas, some of them to a scale of 80 inches to the Moon's diameter. Mr. VICTOR NIELSEN, of Copenhagen, has produced some excellent enlargements of limited regions on a scale of more than

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*I desire to acknowledge the grant of a sum of money to the Lick Observatory from the World's Fair Commissioners of Santa Clara County, California, in aid of this exhibit, and to point out that without it our success in making satisfactory enlargements on a large scale would have been still further postponed.

60 inches to the diameter; and Professor WEINEK and Dr. SPITALER have also made admirable enlargements of limited areas on scales of 120 inches (24-fold), which represent the finest details of the original negatives with perfect accuracy and with precise definition. In special cases, enlargements of 360 inches (71-fold) to the diameter have been made. The last plate in Professor WEINEK'S memoir (plate XIV, of *Tycho*) corresponds to a 24-fold enlargement, and is on a scale of 120 inches to the Moon's diameter. It has been selected from a number of other 24-fold enlargements (all equally good), in order to present a specimen of the latest results attained. It is said that other astronomical photographers have made successful enlargements from our negatives on very large scales, but I have seen no specimens of their work. Excellent enlargements have also been made by Messrs. HENRY and W. H. PICKERING from the Moon negatives of the Paris and Harvard College Observatories, respectively; many of them on large scales.

It is therefore quite clear that a map of the Moon on the scale of VI or even of X feet to the diameter is entirely practicable; and that, for special purposes, enlargements corresponding to a greater diameter may be advantageous. It may fairly be said that the picture of *Tycho* (plate XIV of this volume) is as good as can be obtained from the original negative in the focus by purely photographic processes. It has been reproduced by the autotype process, on stone, by ANGERER & GOESCHL, of Vienna.

Extensive experiments have been made in the matter of *reproducing* the enlarged drawings or negatives in large editions. Trials have been made of lithography and of various photographic processes.* It has been found that the autotype process just named (plate XIV) and the photographic reproductions on copper through a carbon transfer (heliogravure; see the various plates in this volume) are on the whole most satisfactory, if we except direct silver printing from the negatives. It should always be borne in mind that the originals are very much superior to even the best reproductions, both in definition and in the representation of faint contrasts of light and shade.

Through the introduction of Professor WEINEK, and by the great kindness of General-Major RITTER VON ARBTER, the k. u. k. Militär-geographisches Institut of Vienna undertook to make heliogravures from Professor WEINEK'S drawings and from the photographic enlargements of the Lick Observatory negatives. The results are most successful, as their plates in this volume will show. One of the heliogravure plates (No. IV, August 31, 1890) made by the Photogravure Co. of New York is an absolutely untouched copy of an enlargement made here, and must also be considered as a distinct success. All the other heliogravures were reproduced by the Geographical Bureau of the Austro-Hungarian War Department. None of them have been re-touched except by darkening the background.

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* See *Publications of the Astronomical Society of the Pacific*, vol. III (1891), page 333; IV, 81, 114 *et seq.;* V, 1, 139.

Mr. WALTER W. LAW, of New York City, a friend of the Observatory, generously provided a fund to cover the considerable expense of making the plates of the Moon. All such plates in this volume are the gift of Mr. LAW. The grateful thanks of the Observatory are offered to him for this very opportune aid, without which the present volume could not have appeared at this time.

The Negative Plates and their Development.

Until the latter part of 1892 SEED plates (No. 26x) were exclusively employed, and various developers were used. Since that time we have ordinarily employed a very rapid plate (about twice as fast as the first named) sold to us by the CRAMER Company. The emulsion from which this latter plate was made was accidentally obtained by the makers, and has been of great service to us.

Mr. COLTON has developed the negatives by the following formula:

Pyro Developer.

Water	64 ounces.
Sodium sulphite	5 ounces.
Sodium carbonate	4 ounces.

Dissolve, and add ½ ounce salicylic acid dissolved in 2¾ ounces alcohol. For use, add 10 grains of pyro to each 2 ounces of above solution. For landscape work a weaker solution than the above is preferable. Over-exposure can be restrained with a few drops of potassium-bromide solution. For convenience in the Lick Observatory work instead of dry pyro, a solution has been used, made as follows:

Pyro	1 ounce.
Sodium sulphite	80 grains.

Dissolve in water to make 11 ounces of solution, and add 20 drops of sulphuric acid. Each dram contains approximately 5 grains of pyro. Use one dram to each ounce of the alkali solution. This developer was the result of a series of experiments made under the direction of Professor W. H. PICKERING, in 1888, by Mr. BLACK, assistant in the Harvard College Observatory. It was found well adapted to the development of faint objects, and was used on the chart and spectrum plates of the HENRY DRAPER Memorial.

Positive copies and enlargements are usually made on EASTMAN transparency plates, or on plates CARBUTT A or B. They are developed as follows:

Hydrochinon Developer.

No. 1.

Water	120 ounces.
Sodium sulphite	10 ounces.
Hydrochinon	2 ounces.
Potassium bromide	10 grains.

Thoroughly dissolve (heat may be used, with stirring, but without boiling). Filter.

No. 2.

Water	32 ounces.
Potassium hydrate	1⅓ ounces.

Use one part of No. 2 to eight parts of No. 1 (*i. e.*, a dram to an ounce). When fresh developer is applied to the plate, it should be diluted with about half its bulk of water. Use repeatedly, strengthening with freshly-mixed developer as needed.

There are a few elementary principles which must be constantly kept in mind in the making and interpretation of astronomical photographs, and although they are simple, it does not seem to be useless to speak of them separately and in some detail in this place. In the first place, it is always desirable to have at least two negatives of the same object, if possible. Every sensitive film contains some flaws and defects, and, to be sure that a certain feature in the picture really represents a feature in the object, it is always desirable, and sometimes essential, to have duplicate negatives at command. It is not always possible to obtain two such negatives; as, for example, in the case of the photograph of a comet. Such a negative must usually be taken with a long exposure in order to bring out the very features which we seek to represent, and it is ordinarily impossible to make more than one exposure upon a comet *per* night. A negative taken on a subsequent night may not show the same features in the comet. It does not follow that these features did not veritably exist because they are not verified by a second negative. But whenever it is possible—as in negatives of star-groups, nebulæ, planets, the Moon, the Sun—negatives should be made in duplicate, and preferably one directly after the other, with slightly different exposures. At the Lick Observatory all negatives of the Sun, Moon, and planets are so made, whenever it is practicable. If two or more such independent negatives have been secured, and if we find the same feature plainly marked in all the negatives, it is safe to say that this feature really exists in the celestial object which has been photographed. It is not an error common to all the negatives. If such an object (as, for example, a rill on the Moon) is found on two or more independent negatives, it exists. It does not need to be verified by visual observation, and such visual verification adds no weight whatever to the original discovery on one negative and to the verification of that discovery on others. The observation is complete when the object is clearly visible on two or more independent plates. As a matter of fact, we accept much less satisfying evidence than this when we admit the existence of certain features in a sun-spot or of a comet for example, of which we possess but a single plate. In the case of delicate rills on the Moon, which have been clearly exhibited on several photographic plates, a visual observation to verify them is often a pure waste of time. Their visibility depends very greatly upon the particular phase of the Moon at the instant the plates are exposed. In a few hours the phase changes, and they cannot be again seen until the illumination is again suitable. Hence, visual verification should be made, if at all, on the same night as the photographic discovery, if economy of time is an object. When Professor WEINEK'S first discoveries of new craters, new rills, etc., were made on the Lick Observatory negatives which form the collection of the Observatory of Prague, I verified them on other independent negatives belonging to the collection retained at Mount Hamilton. Some of the earlier discoveries I likewise verified visually with the telescopes of the Observatory. When the phase was right the verification was easy. In some cases it was extremely difficult, because the illumination had materially altered since the photographic record was made. I very soon discovered that the amount of time required for such visual verifications was entirely out of proportion to the results, especially as absolutely no additional certainty was thus attained. A feature discovered on one negative and verified on others, or even on another, exists; and no additional *certainty* can be attained by new photographs, or by a visual verification, although new details may be detected.

It is of interest to know the dimensions of the smallest objects (as craters, rills, etc.) which can be registered on the photographic plate. The sensitive plate is composed of grains of silver of about 0.0002 inches in diameter, which are separated from each other by areas relatively empty of silver. These areas are of the same order of size as the grains. 0.0002 inches on the focal negatives corresponds to about 0″.07 of arc, or to about 0.08 of an English mile on the Moon itself. A crater on the Moon which is less than about 0.1 of a mile in diameter will therefore form an image on the plate whose absolute dimensions are approximately the same as those of the grains, or elements of structure, of the plate itself, and hence, in general, such an image will be confused with this grain, and cannot, generally, be made out. In several papers* Professor WEINEK has given instances of very small craters and narrow rills on the Moon independently discovered on the Lick Observatory negatives and sufficiently verified. The diameters of some of these craters are 0.3, 0.15, of an English mile. Other cases of the sort, as yet unpublished, could be cited. These measures show that under suitable circumstances of illumination, etc., the Lick Observatory negatives will depict craters and rills whose absolute dimensions are comparable with the size of the grains of the sensitive plate. It is clear, therefore, that the negatives are nearly as good as they can be made on the sensitive plates now in use. It is to be observed that it is necessary to have every condition of steady atmosphere, correct exposure-time, proper development, suitable illumination, etc., in order to register such minute features, or in order to depict small differences of tint on the floors of crater-rings, etc. When these conditions are right, the negatives will show such features on the Moon.

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* *Sitzungsberichte*, Imperial Academy of Sciences of Vienna, July 6, 1893, and January 11, 1894; *Publications of the Astronomical Society of the Pacific*, vol. V, 1893, page 158, etc.

Any particular negative will only show the features which the exposure, illumination, etc., are fitted to depict. To give *all* the minute objects in a particular area on the Moon several, or many, individual negatives must be made; just as to complete a drawing of this area by visual observations several, or many, observing nights must be spent in the work. Each negative corresponds, not to the completed map, but to a single one of the nights devoted to such a purpose. The completed drawing of a large crater-ring on SCHMIDT'S map, for example, represents the observations of many single nights.*

A half dozen negatives of such a crater, taken under suitable circumstances, will record all, or nearly all, of the objects to be found on the map, each one true in every detail. The negatives will also show many features *not* given by the map.

In order to obtain all the information which such a set of negatives contains, it is necessary to enlarge them either by photography or by drawing, and to make positive copies of them on glass.

If we take the Moon of six days old, for example, as the object to be photographed, we see at once that it consists of different areas varying greatly in brilliancy from the dark terminator to the bright limb. With an aperture of 8 inches to the 36-inch telescope, and rapid plates, an exposure-time of two seconds is quite sufficient for the brighter regions; while four or more seconds is not too much for parts of the terminator. Adjacent parts, however, are intensely bright, and two seconds is more than sufficient for some of them. The best average pictorial effect for the whole Moon—the best photographic picture—is obtained by an exposure-time of about three seconds. While the original pictures are being exposed in the telescope, it is well, in each case, to make a *series* of negatives, varying the exposures from two to four seconds. The motion of the Moon in four seconds is, generally, not enough to seriously affect the definition of the original. Some parts of the Moon will be best shown on certain negatives, while other parts are best seen on others of different exposure-times. When such a series of negatives is made, the development of each plate should be so chosen as to give the best relief to the particular regions for which the exposure of this particular plate is appropriate. The development should not be made for the purpose of giving the best general, or average, effect over the entire surface of the Moon. The non-scientific photographer seeks such an average pictorial effect for landscapes, etc. For most astronomical purposes, it is better to sacrifice this general effect to the particular excellence of special regions. It is obvious that no one exposure-time can be exactly suited to bring out all the features of a surface lighted as is that of the Moon. A series of plates with different exposures and with different developments is required.

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* SCHMIDT enumerates special observations of *Copernicus* on 31 nights in the years 1842–1873, for example, and no doubt he observed this crater on many other unrecorded occasions.

When such a series of plates is obtained, each negative gives a certain set of features, or certain areas, better than any other negative, as has been said. To obtain all the information from the negatives which they are capable of giving, they should now be copied by contact, or otherwise, producing a series of positives on glass. The artificial light used for copying (in our case, the illuminated porcelain shade of a Rochester lamp of 16-candle power) is placed at a distance of 3 feet; the contacts are usually made on EASTMAN transparency plates. Suppose the best general pictorial effect in the positives is obtained when the exposure to the lamp-light is about one minute. (This exposure must be found by trial for each negative to be copied, and for each box of plates; it varies, in our practice, from say thirty seconds to two minutes.) Other positives should now be made from the negatives (keeping the lamp at the same distance), with exposures of say half a minute, two minutes, three, four, etc. Each one of these positives should be developed so as to bring out the particular features for which its exposure is appropriate, and not so as to produce the best average pictorial effect over the whole Moon. The original contrasts of the mother-negative, which is thus copied, can be very greatly changed by this process. The definition of the plates is not changed. Each feature is in its right place and in its right form. But certain features, which are scarcely visible in the original, can be made almost as prominent as we please by suitably timing the copies. For instance, a negative of the full Moon, exposed so as to make the best picture, shows small crater-rings like those near *Nicolai*, for example, in a very inconspicuous manner. If a contact positive is made from this negative, choosing the exposure so as to produce good pictorial effect merely, these small rings are still difficult to distinguish clearly. But it is perfectly practicable to copy the original negative, and to alter its original *contrasts* (only) in such a way as to make these and other similar crater-rings almost the most definite features of the surface. Such a copy as the one last named is, obviously, the plate upon which these particular craters should be studied and measured. Other plates are suited to exhibit other features, as rills, the bright streaks from *Copernicus*, those from *Tycho*, etc.*

If we seek to obtain the maximum amount of information from the original negatives, some process like this must be followed. The plate of *Mare Crisium* (2-fold enlarged) in this volume is an accidental example of this process. In copying the original plate sent from the Lick Observatory for making the heliogravure, all the contrasts have been made far harsher than they are in the original. The cometic tails to the twin craters *Messier* are only shown for a fraction of their real extent, while the craters themselves have been accented unduly. Such a plate is eminently suitable for making measures of the position of such craters, but it is not adapted to showing feeble contrasts of light and shade. These are, in great measure, lost, not because they are not in the original, but because the photographic manipulations, etc., which have been employed have sacrificed the contrasts in order to gain a different effect.

If any one is not convinced of the advantages of this process by reading what goes before, he should actually make for himself the series of positives which I have described. A great advantage in using *positives* is due to the fact that all the features are presented in their natural contrasts—bright regions on the Moon are bright in the plate. Certain features are often very hard to make out in the negatives until they have first been located on suitably-exposed positives. On the other hand, negatives are especially suited to disclose certain other features—rills, for example. If glass positives are carefully made by contact, very little is lost in definition by the copying, though copies in the camera are usually somewhat better.

Everything which has just been said of positive copies by contact applies (the necessary changes being made) to enlarged copies made in the camera. A negative or positive of the Moon, which is only five inches in diameter, is too small to exhibit most features to advantage. It is, in fact, a pretty picture, and it is very little more. The simple negative contains every datum that can be derived from the particular exposure which it represents; but it does not always present the data in the most convenient and legible form. If the original negative is enlarged in a satisfactory manner, details which are too small to be readily seen will become obvious. The degree of enlargement will depend upon the particular feature which it is desired to see well. In general, the greater amplifications are more suitable to bring out definite features of small angular dimensions, and the lesser amplifications are more suitable for exhibiting broad and diffused areas. For example, enlargements of our Moon negatives from 10 to 25 diameters show small craters, narrow rills, etc., in a very satisfactory way, when such features cannot be seen at all by examining the original with an ordinary hand-magnifier. On the other hand, the different shadings on *Jupiter* are seldom so well seen with an enlargement of 20 diameters as they are with one of 10. In each case the proper enlargement to exhibit a particular feature in the very best manner must be found by trial, and this can always be done by a faithful and skilled photographer. There is a distinct limit set to the degree of enlargement which is advantageous by the size of the grain of the sensitive-films employed in making the original negative, and in those upon which the enlarged copies are made. It would be easy to give these limits from measures which we have made upon the grain of the films which we employ. It is, however, not necessary to do more than to state the practical results of many experiments. So far no material advantage has been gained by enlarging our original pictures of the Moon more than 25 diameters. In making this statement I add, in order to avoid misunderstanding, that material advantage is gained in most cases, by enlarging up to this limit.

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* See *Publications of the Astronomical Society of the Pacific*, vol. III, page 250.

The next steps forward in lunar photography seem to depend upon two things:

1st. In obtaining plates even more sensitive than those which we have employed in order to shorten the exposure-times of the original negatives.

2d. In reducing the size of the grain of the sensitive films used in the telescope, and also in the enlarging camera, without diminishing the sensitiveness of the former plates. It thus appears that future improvements depend more upon the manufacturer of plates than upon the astronomer who uses them, or upon the artist who makes the photographic lenses, provided refracting telescopes are employed. I have had comparatively little experience with reflectors; but it is certain that a reflector of good figure possesses important advantages in many photographic problems, and I have hopes that the equipment of the Lick Observatory may be strengthened, at some future time, by the addition of such an instrument.

In making direct enlargements in the telescope one of two processes must be followed. Either the whole telescope must be moved, both in R.A. and N.P.D., to follow the Moon during a period of two or three minutes; or the photographic plate itself must be so moved, the telescope being driven to sidereal motion and a mark on the Moon itself being kept on the wires of a guiding eye-piece.* Nothing material is gained by altering the rate of the driving-clock in right ascension. Experiment has shown that the first process is not a practical one with a telescope so long and so heavy as our own. I doubt if it can be successfully employed with telescopes having more than 15 inches aperture, unless, indeed, the instrument be mounted like the new photographic refractor of Meudon, with a separate guiding telescope (visual) secured in the same tube that holds the photographic objective; and, even in this case, the slow motions must be extremely well made to insure the necessary delicacy. The second method has been tried here and abandoned, at least for the present, for the reason that its success depended upon finding a brilliant guiding-mark on the Moon near the region to be photographed. Only such regions could be photographed as had good guiding-marks conveniently situated. Hence it was usually impossible to photograph a particular region at a desired time. If one is willing to select good guiding-marks and to photograph such regions as chance to be adjacent to them, I think that some degree of success may still be had in this way, in spite of various mechanical and other difficulties, and of the comparatively long exposures required (two, three, or even four minutes of time for objects near the terminator and for enlargements of 5 to 8 diameters). It is, however, true that we have never yet obtained enlargements by this method which were so good as equal enlargements in the camera from negatives taken in the principal focus. With a telescope like our own the secret of success seems to be to photograph the Moon in the focus on the quickest possible plates, with the shortest possible exposures, especially if rapid plates can be manufactured which have a fine grain, which seems to be probable. Excellent direct 5-fold enlargements of *Jupiter* have been made, but in this case we have short exposures (three seconds) and no appreciable proper-motion of the object to deal with. The effect of wind on a long-focus telescope is considerable. The photographic focal-length of the 36-inch equatorial is 47½ feet. If a direct enlargement of 8 diameters is employed the effect of wind tremors on the negative is the same as if we were photographing in the principal focus of a telescope nearly 400 feet in length. If the telescope is used to make direct enlargements (as above described) the guiding of the plate so as to avoid the effect of tremors, etc., becomes a matter of extreme delicacy.

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* The eye-piece G of the preceding wood-cut cannot be used for this purpose.

If we compare any one of the plates in this volume with the Moon itself; and if we then compare one of the best maps (as SCHMIDT'S or MAEDLER'S) in the same manner, we shall find the plates to have an immense superiority in very many respects. The landscape in the plates is a life-like copy of the lunar surface, while the best map is very unsatisfactory in its relief. It is often quite difficult to interpret the finer details of SCHMIDT'S drawing, in spite of its general excellence. Moreover, even the best topographical drawings made at the telescope will be found to contain material errors, as they must be constructed piece by piece, and as the joining of the separate pieces can never be wholly satisfactory. Compare, for example, SCHMIDT'S elaborate topography of *Copernicus* or *Tycho* with the plates of these craters in this volume. It will be seen that the plates are entirely comprehensible at the first glance; while it requires considerable study to interpret the conventional topography of the map. When it is a question to decide whether or no changes have taken place in a certain lunar region, by comparing such a map with the image in the telescope, the decision is frequently a matter of no small difficulty on account of the unavoidable ambiguities and imperfections in the map itself. Owing to the fact that the map contains all the objects which have been seen by the observer during many years, while each photograph only exhibits the features which the illumination, etc., of one particular moment was fitted to show, an unreflecting comparison of map with photograph may lead to an entirely erroneous estimate of the relative excellence of the two representations. A trained eye can see with a telescope and a high magnifying power a certain class of objects (as for example, extremely small, well-defined crater-pits) better than they can be photographed with the same telescope on our present sensitive plates. The visibility of this class of objects depends chiefly on precise definition of minute contours.*

On the other hand, there is a multitude of objects which can be photographed with the great telescope, with its aperture reduced to 8 inches, which are extremely difficult to see with the full aperture of 36 inches. It is absolutely certain that these objects veritably exist on the Moon, for they are found on all the negatives made during a certain night, and on other negatives made on other occasions. The visibility of objects of this second class (as rills, streaks, terrace-formations, and the like) depends on contrast, and not so much upon definition. The visual contrast of two adjacent lunar areas, *a* and *b*, is often too small to allow the eye to discriminate them while it is exposed to the glare of strong moonlight. If we reduce the general glare by using colored shade glasses, we usually make both areas *a* and *b* invisible. On the other hand, the photographic plate often exaggerates the contrast (as is well seen in the case of small features situated in the dark seas), and the two areas are readily seen on the developed negative. Moreover, the primitive photographic contrast can be again increased by subsequent copying, as has been previously said. There are many objects on the Moon, yet uncatalogued, which belong to the first class mentioned (small, definite contours, whose visibility depends chiefly on definition); but, if we may judge by our experience with the Mount Hamilton negatives, there are indefinitely more objects of the second class (those whose visibility depends chiefly on contrast); and the photographs are very greatly superior to eye drawings for registering such features.

The chief advantage of the map is, that it is a convenient method of representing, on a single sheet, *all* the features which the observer has detected and recorded during the whole course of his observing. Each one of the minute craters, or small rills, which he has seen during a long period of years with different telescopes and under all conditions of illumination, can be marked down in place; whereas, each photograph depicts the surface as it is seen at one particular instant, and phase of illumination, only. It requires a *series* of photographs, therefore, to show the minute detail which can be exhibited on a single sheet of the map. Leaving this single advantage of maps to one side, it seems that, in other respects, the photographs are superior. Each one of them exhibits all that it shows at all, in its true value and relief. The definition of the photographs is entirely satisfactory up to a certain point. Beyond that point we must have recourse to a map constructed from visual observations, with comparatively high magnifying powers. If such a map is required, it should be made by a skilled draughtsman and artist, *using the photographs as a basis*. The Prague observations since 1884 have contained beautiful drawings (reproduced by heliogravure in an excellent manner) made by Professor WEINEK himself by means of the 6-inch refractor of that observatory. These drawings represent the very best work which can be done with an instrument of this size in the delineation of lunar craters. The present volume contains drawings or enlarged photographs of some of the same craters. In order to appreciate the great advances which have been made in the study of lunar topography, the reader should compare Professor WEINEK'S drawing of *Copernicus* in this volume with his drawing of the same crater in the Prague Observations for 1884 (No. 14); or Professor WEINEK'S photographic enlargement of *Tycho* (in this volume), with his drawing made with the 6-inch equatorial (No. 11 in the Prague Observations for 1884, No. 1 in the Prague Observations for 1885–7). The early drawings in the Prague Observations are the best that can be obtained with a 6-inch equatorial, but they can scarcely be compared with the results given in the present volume. Yet they have been made by the same observer, with the same care and the same eminent skill. The difference is entirely due to the advantages afforded by the Lick Observatory negatives. The reader who wishes to fairly appreciate the immense progress which has been attained should actually make the comparison which is here suggested. It is entirely due to a change of the method of observation, since the actual work in both cases was done by Professor WEINEK himself.

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* See, however, in this volume, Professor WEINEK's discussion of his drawing of *Copernicus*.

The foregoing introduction gives some account of the nature of the work done up to this time at the Lick Observatory in photography of the Moon. The following pages by Professor WEINEK describe the investigations at Prague, and some of the results obtained. The original descriptions were written by Professor WEINEK in German. They have been translated by Mr. OTTO VON GELDERN, Mr. F. R. ZIEL, and by myself; and the translations have been revised by Professor

WEINEK (except the chapter on *Vendelinus*). The engravings illustrate the text and reproduce the original negatives as well as possible, thanks to the gift of Mr. LAW. The proofs of the discoveries of new features on the Moon are to be found in the originals, however, not in the plates herewith. Copies of our original negatives have been sent to many observatories and academies of science; the most complete collections being at Prague, with the Royal Astronomical Society of London, and with the Smithsonian Institution; and whatever is here described can be verified on these copies by any one who will take the necessary pains. A cursory examination will not suffice.

It will be seen that Part I of the present volume is a record of experimental work in many directions. If any one will consider the state of the problems with which this book is chiefly concerned before our work was begun, and will compare it candidly with the preliminary results here exhibited, I submit that the conclusion must be that the joint work of Professor WEINEK and of the Lick Observatory has already led to results of consequence, and especially, that the way has been found in which future advances must be made.

Part II of this volume is a report on certain prisms of optical glass, belonging to the Lick Observatory, which was prepared for the Lick Trustees in the years 1887 and 1889 by Professor C. S. HASTINGS. This admirably exact investigation of the glass of which the great objective is made would have been printed long since if it had been practicable to do so.

Part III is an investigation of the division errors of one of the divided scales of the measuring-engine of the Lick Observatory, by Mr. O. H. TITTMAN, Assistant in the U. S. Coast and Geodetic Survey. The Lick Observatory measuring-engine has been succinctly described in Vol. I of the *Publications* (page 76). Before any accurate measures could be made with it, it was necessary to know the division errors of one (at least) of its glass scales. Professor T. C. MENDENHALL, Chief of the U. S. Coast and Geodetic Survey, was kind enough to undertake this work in our behalf, and Mr. TITTMAN, of the Survey, accordingly investigated the scale and determined a table of corrections to each division. Mr. TITTMAN'S report to Professor MENDENHALL is printed in Part III. I beg to express the sincere obligations of the Lick Observatory for this material assistance, and for the permission to print the report here.

Part IV is a report on spectroscopic observations of nebulæ, made with the 36-inch equatorial of the Lick Observatory, which Professor KEELER has prepared. It has not been practicable to issue this important memoir before now.

EDWARD S. HOLDEN.

The Lick Observatory, February, 1894.

PREFACE.*

BY PROFESSOR L. WEINEK.

It is due to the friendly suggestion and to the subsequent ready coöperation of the Director of the Lick Observatory, that I was originally induced to undertake the following studies of the lunar surface as exhibited in the splendid focal negatives of the 36-inch refractor of the Lick Observatory, and that I have been enabled to prosecute such studies with ever-increasing success during the past three and a half years.

In November, 1889, Professor HOLDEN proposed to send the best Moon negatives of the Lick Observatory to Prague, in case I was disposed to make use of them for detailed studies of the Moon's surface—to use them either as a basis for the continuation of my drawings of special lunar regions which I had begun in 1884 with the 6-inch telescope of the Prague Observatory, or for independent investigations founded on the photographs alone. I accepted this proposition with pleasure—a pleasure all the more lively, because it thus became possible for me to have the advantage, indirectly at least, of observations with the greatest telescope in the world. If the studies here presented are fitted to contribute to the advancement of our knowledge of the Moon, as I believe that they are, the credit is due, in the first instance, to the Director of the Lick Observatory. It is my agreeable duty to express in this place my sincere thanks for the cordial aid and assistance which my Moon studies have constantly received at his hands.

My very first glance at one of the Mount Hamilton *dia-positives* (that is to say, a positive copy on glass, made by contact from one of the focal negatives of the year 1888), at the beginning of the year 1890, made it clear that the study of such transparencies would be far more fruitful than any study of positive prints on paper; that a careful examination of such plates would everywhere disclose rich and manifold details of the lunar topography; and that, in consideration of the wonderful relief of the photographic lunar landscapes, it was obvious that an enlarged representation of the photographic plates—a bird's-eye view—as exact as possible, would be of the highest value to our comprehension of the structure of the surface of the Moon. At the same time I became convinced that such photographic plates, upon which the lunar diameter was about 13 *cm.*, were of sufficient sharpness and of adequate size to constitute an important advance over the earlier (and excellent) results of RUTHERFURD, WARREN DE LA RUE, and DRAPER.

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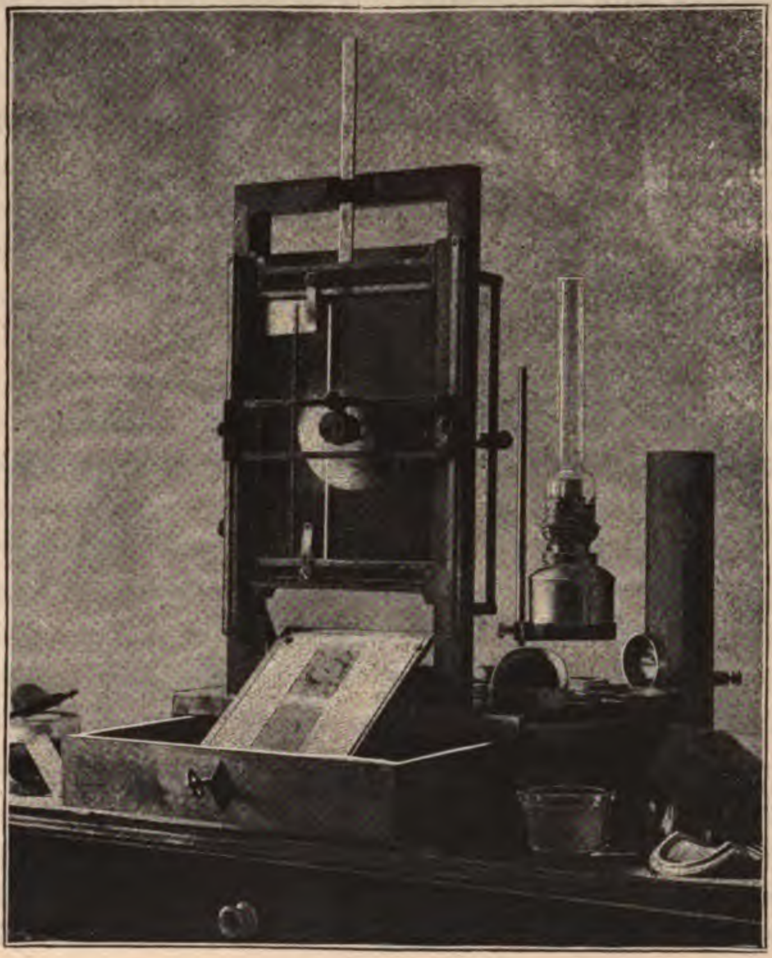
*Translated by EDWARD S. HOLDEN.

I therefore resolved to undertake *enlarged* representations of the Mount Hamilton negatives, and at once began experiments to decide upon the most appropriate methods of work. The methods of direct photographic enlargement were at that time so unsatisfactory, and the results which had been so far obtained were so much behind the original negatives in many respects (and notably in respect of sharp definition), that I was not ready, at that time, to adopt them, in spite of the facility with which direct enlargements, such as they were, could be produced. I decided, therefore, to begin my work by making enlarged pencil drawings (to be subsequently retouched and finished with India ink), from the original plates examined by transmitted light under a magnifier.

When the artist possesses the necessary training, such enlarged drawings can be made with a very high degree of completeness, and with almost absolute fidelity if the necessary pains are taken; and at every stage in the progress of the work it is possible to control the drawing, and to correct it if necessary. Two different methods of making enlarged drawings were open to me. In the *first* method a faint photographic enlargement could be made, on suitable paper, and to the required scale, and this enlargement could be brought up to the full intensity of the original by retouching. In order to preserve the high lights of the picture, it is necessary to make the first photographic copies extremely faint. But in this way, only the principal features of the image are photographically depicted, and the process of retouching becomes almost as laborious as the making of a completely new drawing. Such was the result of my experiments in this direction. In the *second* method the whole image is drawn on plain paper without any photographic assistance. This method requires great facility in the manipulation of brush and pencil, as well as extreme patience and long practice in the difficult, almost infinitely fatiguing, work which is demanded if the aim of the artist is to present a mathematically exact enlargement of the original, which shall be true in all its parts.

For either method it was necessary to have an apparatus for the convenient examination of the transparencies under high magnifying powers. For the lack of such an apparatus, the excellence of the Mount Hamilton negatives has frequently been underestimated by persons who have only examined them with a magnifier held in the hand. The necessity for such an apparatus is obvious, even in casual examinations. If one is to make drawings from the same object for months and months together, as I have been obliged to do, it is absolutely indispensable to have the original plate held in the most convenient manner, with the eye-piece in a fixed relation to the plate, and to be able to alter the illumination at will until the appropriate brilliancy is secured and maintained. In this way only is it possible for the artist to obtain a complete and thorough comprehension of the picture itself, and to be certain to lose nothing of the finer detail of its structure. My first apparatus was constructed so as to hold but a single plate (8x10 inches), but a second apparatus permitted me to fix *two* plates side by side. To facilitate the comparison of the two plates, the frame holding them is so constructed that any two lines on the two plates can be made parallel, and that any two points can be brought to the same height, etc. A full description of this device is given in the *Prager Astronomischen Beobachtungen*, 1888–91, page 50, with a wood-cut, which is here reproduced. It is only necessary to add, here, that while making enlarged drawings a plane-parallel glass reticle (divided into squares of 1 *mm.* or ½ *mm.* on the sides) is firmly held against the plate, with the ruled surface next to the film. The paper upon which the drawing is made is also ruled into suitably enlarged squares, corresponding to the squares of the reticle. During the whole course of the drawing—weeks or months—the glass reticle remains unchanged in position.



After the contours have been drawn in, and after the first light shading with the pencil is completed, the glass reticle, with its somewhat confusing net-work of lines, is removed, and the drawing is completed in India ink, step by step, area by area, with the greatest care.

The *first* method was employed *only* in the 4-fold enlargement of *Mare Crisium*, since it was found that the excellence of the result was greater when the photographic outlines were almost or entirely absent, and when the whole dependence was placed upon the skill of the artist. This experiment fully showed that the *second* method of making enlarged drawings was superior, in spite of the exceedingly great labor involved.

The *second* method was accordingly employed (using the glass reticle) in making the following series of drawings: *Archimedes*, 10-fold enlarged, in two drawings of opposite illuminations; *Arzachel*, 10-fold enlarged, also in duplicate; as well as the following-named regions, each 20-fold enlarged—*Petavius*, *Vendelinus*, *Langrenus*, *Flammarion*, *Eratosthenes*, the region west of the *Riphaeus* mountains (also in duplicate); and *Copernicus*. Finally, *Capella* has been drawn 40-fold enlarged from two, and *Taruntius*, C, from three different plates. Besides these, very many drawings of other regions have been made, sometimes on small scales, sometimes simply sketched 10, 20, and 40-fold enlarged, whenever interesting photographic discoveries have been made. The enlarged net-work was allowed to remain on the completed drawings of the western regions of the *Riphaeus* mountains and of *Capella* and *Taruntius*, C, in order to facilitate comparisons and identifications of the different objects on different photographic plates. The drawings just mentioned, and particularly that of *Capella*, have fully demonstrated that these Moon-photographs are capable of exhibiting the finest rills and the most minute craters, even when their dimensions are not above 0.5 *kilometers* (0.3 of an English mile). My appreciation of the multitude and of the significance of the details on the Mount Hamilton plates has been of gradual growth; and this fact will explain why it is that my drawings are continuously more detailed and more complete, as they are later in the series. The most complete drawing—*Copernicus*—is thus the latest, and it was not finished till I had spent 224¾ hours of actual work upon it.

The fact should now be emphasized that all my drawings have been made with the extremest possible care and precision, and that they show *everything* that is to be found in the *dia-positive* plate from which they are copied. I have omitted only such features as are obviously scratches, or the very smallest defects in the film. On the other hand, since I had a free choice of the regions to be depicted, I have chosen *only* such as a previous very careful examination had shown to be very free from the defects referred to. The notes accompanying each drawing give an account of the comparisons which have been made between independent negatives showing the region in question. As the drawings in Prague were made from *dia-positives*, and not from the original negatives, one source of possible error still remains. If the *dia-positives* are entirely perfect copies, no error can arise from their use, naturally. On the other hand, small differences—as a lack of precision and definition in a few of the smaller objects—may arise if the positive is not a perfect copy of the original. The general excellence of the photographic work of the Lick Observatory has led me to assume that the copies in my hands were practically perfect, but I have nevertheless considered it to be necessary that my enlarged drawings made from positives should be compared with the originals remaining at Mount Hamilton, whenever possible, especially in the earlier stages of my work. These comparisons have been made by Professor HOLDEN, and I may be allowed to quote here a few sentences from his letter of March 8, 1893, regarding my drawing of *Petavius:* "I did not remember that you had asked me specifically to compare your drawing of *Petavius* (from a positive) with the original negative, from which the positive was made (August 31, 1890, $14^h 27^m$), and to let you know the result. I, however, made the comparison long ago, and the result was in this case (as in every other one) that your drawing faithfully represents the original. You will remember, however, that these fine rills look very differently in a *negative* and in a *positive*. I found one or two of the finer rills hard to make out in the original negative. I therefore had another positive made here, and every essential feature of your drawing was verified, rills and all. There were some very difficult objects (I forget which ones now) that I was not quite sure of; but I came to the conclusion that if I spent more time on them, I should probably see them as you had drawn them. In this examination of your drawings, as in every other one which I have made, I was struck with the admirable and artistic way in which you have represented the various features (some of them elusive and difficult), and with the minute thoroughness of your examination. You had seen *everything*, and had represented it artistically, so that it was easy to verify. I have told you this before. I regret that I overlooked your request for specific information about *Petavius*."

The table on page 26 gives a list of the more important drawings made by me, together with some data relating to each one.

The present volume contains heliogravure reproductions of the most important drawings of those just named—of *Mare Crisium*, *Archimedes*, *Arzachel*, *Petavius*, *Vendelinus*, *Langrenus*, and *Copernicus*. At the first glance it is obvious that the drawing of *Copernicus* was by far the most difficult. *Flammarion* and *Capella* and *Taruntius*, C, have been reproduced in the journals *L'Astronomie* and *Sirius;* and the latter journal has also printed both drawings of the region west of the *Riphaeus* mountains. Plate XV of this book is a phototype of *Capella* and *Taruntius*, C.

Such drawings as are not reproduced in the present volume of the *Publications of the Lick Observatory* will be subsequently printed in the Prague Observations.

	Mount Hamilton Plate. Date.	Object.	Enlargement.	Actual Time Employed in the Drawing. Hours.	Date at Which the Drawing Was Commenced.
1	1888, Aug. 23, P. S. T.	*Mare Crisium*	4	34¾	1890, June 12
2	1888, Aug. 15, P. S. T.	*Archimedes*	10	44¾	1890, Oct. 16
3	1888, Aug. 27, P. S. T.	*Archimedes*	10	43	1890, Oct. 16
4	1888, Aug. 15, P. S. T.	*Arzachel*	10	42¾	1890, Nov. 23
5	1888, Aug. 27, P. S. T.	*Arzachel*	10	49¼	1890, Nov. 26
6	1890, Aug. 31, 14^h 27^m, P. S. T.	*Petavius*	20	120½	1891, June 23
7	1890, Aug. 31, 14^h 27^m, P. S. T.	*Vendelinus*	20	122	1890, Nov. 24
8	1890, Aug. 31, 14^h 27^m, P. S. T.	*Langrenus*	20	127½	1891, Dec. 7
9	1888, Aug. 15	*Flammarion*	20	71	1892, Jan. 18
10	1888, Aug. 27	*Eratosthenes*	20	25½	1892, Mar. 12
11	1891, July 28, 15^h 49^m 16^s, P. S. T. 1888, Aug. 17	W. of *Riphaeus*	20	18¼	1893, Feb. 19
12	1890, Nov. 17, 6^h 8^m 35^s, P.S.T. 1890, Aug. 31, 14^h 27^m	*Capella*	40	45½	1893, May 3
13	1890, July 20, 7^h 53^m 1890, Aug. 31, 14^h 27^m 1890, Nov. 16, 5^h 53^m	*Taruntius*, C	40	10½	1893, May 5
14	1891, July 28, 15^h 49^m 16^s	*Copernicus*	20	224¾	1893, Jan. 4

During the course of the work which has just been described experiments have been made by various persons, to see if the extremely slow, fatiguing, and arduous method of enlarging the original negatives by drawings might not be advantageously replaced by a direct photographic enlargement in the camera. Such experiments were extensively carried out at the Lick Observatory, usually by Mr. COLTON, and copies of the resulting plates were sent to me by Professor HOLDEN as they were obtained. The present volume gives some examples of these experiments in the plates of *Mare Crisium* (2-fold enlarged by Professor BURNHAM); of *Petavius*, *Vendelinus*, *Langrenus*, and also of the lunar *Apennines* (7-fold enlarged by Mr. COLTON). The latter two plates correspond to a diameter of the Moon of about one *meter* (more exactly, 97.45 *cm.*, or 38.36 English inches), which is the scale of the lunar maps of LOHRMANN and MAEDLER.

The best results of the Mount Hamilton experiments corresponded, on the whole, to an enlargement of about 7 diameters. I have compared such enlarged *dia-positives* under a magnifying power of 6 diameters with an un-enlarged contact positive (from the same negative) viewed with an eye-piece amplifying 42 diameters; the comparison showed that 7-fold enlargements were much inferior in the representation of the finer detail, for the reason that the enlarged grain of the plate had taken on a diffused character. This arises in fact from diffused groups of grains, which give a flaky and ill-defined appearance to the image; and this image becomes more and more confused the higher the amplification. The representation of the very finest details of the photographically enlarged image—such as were first brought out in my drawings, for example—are by no means comparable with the results from the drawings. The same criticism with respect to the finer details applies to direct photographic enlargements made by others, although the plastic effect of many of these enlargements is very fine.

Matters were in this state when in April, 1893, I determined (during the tedious progress of my 20-fold enlarged drawing of *Copernicus*) to experiment in producing direct photographic enlargements, and to endeavor to obtain a grain of the enlarged photographic plate which should be as fine as the same grain seen visually under corresponding amplification. It may be noted that my photographic experience began in 1873, when I was in charge of the German station in Schwerin for conducting experiments in astronomical and photographic methods to be employed in observing the transit of *Venus* of 1874. At that time I investigated the different photographic processes, including daguerreotype methods, with special reference to deformations of the film,* and on December 9, 1874, I successfully photographed the transit of *Venus* at Kerguelen Island. Dr. R. SPITALER, now Adjunct in the Observatory of Prague, formerly assistant in the Observatory of Vienna, had also acquired valuable photographic skill in his experience with the 27-inch equatorial of the latter observatory.

On April 19, 1893, I began these experiments in enlarging, by a method which I reserve from publication at present, and which at once gave very excellent results. The grain of the enlarged plate corresponded in dimensions with the geometrical factor of enlargement, and was from 9 to 10 times finer than the grain of similar enlargements made by others. Moreover, my enlargements reproduced the finer detail of the originals with entire precision. The chief lack of the photographic enlargements in comparison with exact enlarged drawings appeared to be that a single exposure-time did not reproduce *all* parts of the image with the same excellence, which is not to be wondered at; so that it was necessary to make several exposures of different lengths in order to obtain equal excellence in all parts of the image. As a proof of the precision of my method, I may instance the cases of fine rills and craters in the ring-plains *Thebit* and *Eratosthenes*, which I discovered long since by photography, and which I subsequently studied and drew with great care. These rills and craters I photographed with regularly increasing magnifying powers, and determined what amplifications were most suitable for representing them in the clearest manner. Of particular interest in this connection are the following objects: A winding rill, which begins on the high interior north-wall of *Eratosthenes* and runs for about two geographical miles to the valley, as well as several very minute crater-like objects, whose diameter is less than 0.5 *kilometer*. I enlarged *Thebit* successively 12, 20, 39, 50, and 62 diameters, and *Eratosthenes* 21, 38, 53, and 71 diameters. Even the highest powers gave a relatively very fine grain, which corresponded exactly with the visual grain, similarly magnified, and showed the manifold detail with complete clearness. It is obvious that the grain of the original Mount Hamilton negatives (emulsion dry plates) is not to be done away with by any process, but must always remain in the final result. The finer the grain of the original negatives, the finer the grain of the enlarged copies. In the first series of experiments referred to it was only possible to cover a small field of view with the necessary sharpness. Later trials, made after improving the optical and mechanical arrangements of the apparatus, permitted me to enlarge the most extensive wall-plains of the Moon with corresponding sharpness in all their parts, and to secure extended photographic enlargements which leave little to be desired from the standpoint of the selenographer, so soon as one has learned to examine the picture without giving attention to the grain. An example of this work is presented in the present volume in the plate of *Tycho*, in which the original has been enlarged 24 diameters, up to a scale of 3⅓ *meters* to the diameter of the Moon. In all enlargements of the kind, the focusing of the plates has been done and all the exposures have been made by myself in the enlarging-apparatus which I have contrived, while Dr. SPITALER has developed the plates in my presence, and has conducted all the subsequent photographic manipulations, taking the greatest pains at every step.

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* *Die Photographie in der messenden Astronomie*, von Dr. L. WEINEK, Halle, 1879.

With relation to the following chapters of text, which explain the several plates of this volume, it is to be remarked that they chiefly relate to a comparison with the lunar chart of SCHMIDT. My object in these discussions has seldom been to bring forward such new views with regard to the Moon's topography as might be suggested by the plates, since for such a purpose an entirely new nomenclature would need to be adopted, or else each plate would have to be covered with a net-work of squares, and the completed drawings subsequently compared anew with the charts and with the sky. My object has rather been to point out to the reader the most important and interesting features of the landscapes depicted in the plates, in order to bring into prominence the great excellence of the negatives of the Lick Observatory which serve as their ground work, and especially to illustrate the high degree of dependence which can be placed upon results derived from suitable lunar photographs.

It must constantly be kept in mind that the heliogravures, in spite of the fact that they represent the best process of reproduction so far known, give but an inadequate idea of the beauty and clearness of the original negatives; and, furthermore, that in order to obtain the best results from these latter, it is by no means sufficient to hold them in the hand and to inspect them by means of an ordinary hand-magnifier. On the contrary, it will be found essential to fix the negatives in a steady frame, to provide means for the best illumination, and methods of varying this illumination at will, to use magnifying powers of 10, 20, 30, and 40 diameters, and last, and by no means least, to spend not minutes but hours in examining these autographic records. When these precautions are taken the results obtained will be found to justify the labor and time expended. My first trials in this direction were made (in 1889) with a lens magnifying 4 diameters. The drawing of *Mare Crisium* in this volume was my first result. My next experiments are shown in the figures of *Archimedes* and *Arzachel*, which are enlarged 10-fold. *Petavius*, *Vendelinus*, *Langrenus*, and *Copernicus* followed, each amplified 20-fold. Finally, in 1893, I completed the drawing of *Capella*, which is enlarged 40 diameters. The history of these experiments as illustrated by these plates shows that the negatives contain very many features which are not obvious on a first inspection, but which can be found, and verified, by any one who will take sufficient pains.

L. WEINEK.

Prag, *k. u. k. Sternwarte*, March, 1894.

THE MOON TWO DAYS AFTER THE FIRST QUARTER.*

(See the Frontispiece.)

This general view of the Moon, which was taken 2 days 4.6 hours after the first quarter, has been reproduced from one of the best Mount Hamilton negatives at Prague (1891, October 12, $7^h\ 30^m\ 54^s.5$, P. S. T.). The heliogravure (made by the k. u. k. Militär-geographisches Institut in Wien) is of exactly the same size as the original; its diameter from north to south border is 137 *mm.* (5.39 inches). The terminator coincides with *Agatharchides*, and in the northern half of the Moon it passes through the eastern part of *Sinus Iridum.* Unfortunately the heliogravure (which I shall call H, for brevity) is considerably less satisfactory than the negative, N, as is, indeed, generally the case. The frontispiece gives only a feeble idea of the rich detail everywhere presented by the original. On the other hand, the relative brilliancies of the different portions of the illuminated west-half of the Moon are excellently represented in the plate.

The magnitude of the libration in latitude in this photograph is interesting. At a period of mean libration in latitude, the distance from *Tycho* to the southern limb is greater than the distance from *Plato* to the north limb. In the plate, the contrary relation obtains. *Plato* is far within the disc, *Copernicus* nearly on its middle line, and *Clavius* quite on the edge of the visible southern limb. This is to be explained by the circumstance that on October 12, at $15^h\ 30^m\ 54^s.5$, Greenwich mean time, the Moon was nearly at its maximum distance south of the ecliptic, and hence portions of the Moon's surface beyond the north pole were visible to observers on the earth.

The terminator, as shown in H, is not quite the same line as is given by N. This arises from the fact that, in order to secure a very dark background exterior to the image of the Moon, in the heliogravure process, it was necessary to coat the *further* side of the glass-negative with a red pigment. In this process some variations in the true line separating the background and the image were necessarily introduced. Independent of this technical fault, the finer detail in H is not reproduced along the terminator.

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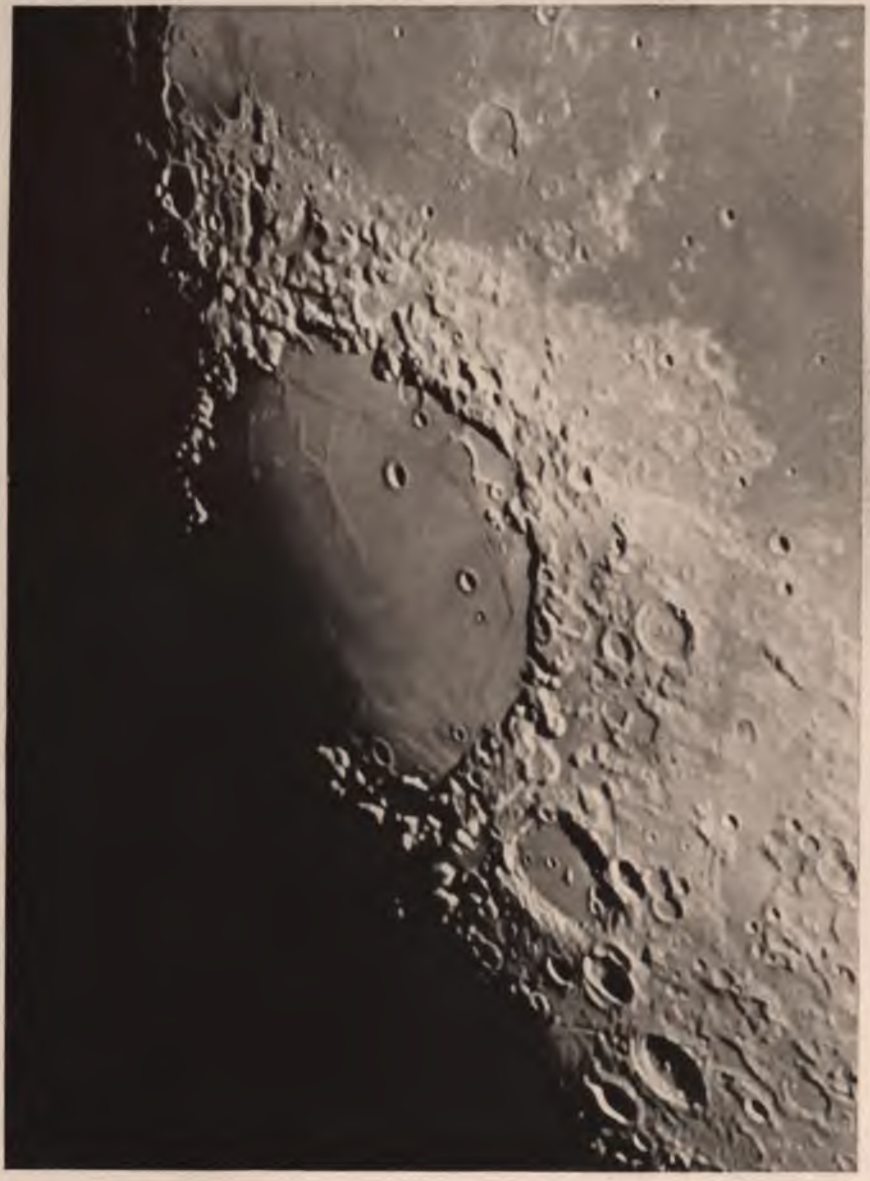
* Translated by EDWARD S. HOLDEN.

How brilliantly the *Riphaeus* mountains and *Euclides* are displayed in N, how full of relief and detail the former appear, is only signalized on H in the larger characteristics. In the same way H fails to depict the string of pearl-like, small craters between *Copernicus* and *Eratosthenes*, the small crater *d* north of *Archimedes*, the striped marking of the inside of the latter ring-plain, etc., while the negative, N, shows all these objects easily and well with the aid of only a simple hand-magnifying glass.

The three dark spots in the interior of *Alphonsus* can be, with difficulty, made out on H, while these are bright and of special intensity on the negative. The bright spots in the image, H, deserve a particular study. The bright *Proclus* is to be seen, although it is by no means the most brilliant object, as the negative shows it to be; the brilliant craters *Censorinus*, *Dionysius*, *Menelaus*, *Manilius*, *Conon*, and *Aratus* (in the *Apennines*); the very bright spots on the northeast wall of *Werner*, west of *Hell* (that is, north of *Lexell;* Q, according to NEISON); east of *Almanon* (crater *e*, according to NEISON, which is easily distinguished as such on N); southwest of *Le Monnier*, west of *Atlas*, etc.—these and others are visible. The twin-craters, *Messier*, with their cometic tails extending eastward, the bright spot, *Linné*, in the eastern portion of *Mare Serenitatis*, are also shown. On the other hand, several objects on the bright ground of the heliogravure are not to be seen, which are readily visible on N; as, for example, the contours of the ring-plains, *Roemer*, *Atlas*, *Hercules*, and others. The bright spots of the heliogravure are dark on the negative, and may readily be overlooked on the latter. It would be highly interesting to compare these spots photometrically among each other from the photograph, and to contrast the order of their intensity, so obtained, with the corresponding order obtained by visual observations with a telescope.

THE ASTOR L.



MARE CRISIUM

DRAWN BY PROFESSOR DR. L. WEINEK FROM THE NEGATIVE
TAKEN AT THE LICK OBSERVATORY ON AUGUST 23, 1888.

DRAWING OF MARE CRISIUM.*

(See the heliogravure plate facing this page.)

The wonderfully fine plastic effect of the Lick Observatory Moon negative of August 23, 1888, especially in its western portions; and, in particular, the vivid impression made upon me by the highly interesting *Mare Crisium* and its surrounding regions, induced me to begin my studies of the admirable negatives made at Mount Hamilton with this object. I may remark that the beauty of this lunar landscape likewise inspired me to commence my telescopic studies of special portions of the Moon (which are printed in the *Annals of the Observatory of Prague*) with the same region on March 14, 1884.

The portion of the northwestern limb of the Moon represented in the plate extends from the crater *Secchi* in the south to *Berzelius* in the north. It was obtained by enlarging the corresponding part of the original negative by means of the camera, 4-fold, upon the so-called "*salz-papier*," which appeared to be suitable for a water-color drawing. The shading was made as light as possible. This enlarged positive copy on paper constituted the basis of my drawing, which required 34¾ actual working hours, and which was especially difficult of execution on account of the fineness of the details.

As the photographic paper copy was printed so faintly as only to give the merest impression of the contours, it would not have been possible to have represented the brilliant lights of the original plate, on account of the unsatisfactory whiteness of the paper employed, if the shadows on the lunar surface had not been made extremely dark. For this purpose, very unctuous colors were necessary, which I finally succeeded in obtaining from Düsseldorf and from Leipzig. The heliographic reproduction of the original drawing must be considered as, in general, highly satisfactory, although it can only incompletely represent the most delicate tones and transitions. This is particularly true of the western borders of *Mare Crisium*, which, in the original, extend farther toward the west, and in which several faint ridges are laid down, not shown in the plate. It is to be remarked that the top of the plate is south, the right hand side east.

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* Translated by EDWARD S. HOLDEN.

If now we compare the whole of the mighty mountain region which surrounds the *Mare Crisium* on the south, east, and north, in its splendid relief on the photographic plate—which shows all the component parts and their grouping, all the plateaux and valleys—with the corresponding delineations of SCHMIDT, MAEDLER, and LOHRMANN, it will be found that each of these accomplished selenographers has succeeded in giving certain parts with remarkable fidelity; but that no one of them has given the whole with anything like completeness.

Taking everything into consideration, the representation of MAEDLER is nearest the truth, and it is very remarkable how nearly his schematic drawings succeed in giving the true effect of this very complicated region. So far as fineness of detail is concerned SCHMIDT is considerably in advance of all his predecessors, yet his work is also susceptible of improvement in many respects. I shall therefore give a comparison with SCHMIDT'S map, Sections XI and XII, which represent the western border of the Moon from *Langrenus* to *Geminus*. The nomenclature employed is (so far as letters or numbers are used) the same as SCHMIDT'S, with occasional additions from MAEDLER or NEISON.

I commence the comparison with the *interior* of *Mare Crisium*. SCHMIDT has represented more longitudinal ridges (in the meridional direction) than are given in the photograph, but these are not always correctly laid down.* The middle ridge, with the southern fork in the latitude of *Picard* (No. 20), is shown by the negative to have this fork more open, with its western branch bent still farther to the west, and with its southern termination less convex, than it is given by SCHMIDT. Again, the characteristics of the ridge to the south and southwest of the crater F are different in the photograph from those in SCHMIDT'S map. In this place SCHMIDT does not show certain areas surrounded by ridges which have a nearly elliptical form, with the longest axis in the meridian. A faint dark line on the photograph is especially noteworthy. This begins at the Cape *Azout* △ (No. 2, △) and extends nearly parallel to the east coast as far as the crater *Picard*, *e*, then approaches this coast and finally curves again east of crater B and takes a direction toward crater F. All selenographers have represented this line (Zug) as a low elevation, but the photograph gives the impression that it is a terrace-like slope of the east side of the interior declining toward the west. I had already noticed this appearance while I was completing my drawing of March 14, 1884, above referred to; and Dr. H. J. KLEIN has made the same remark in *Sirius* (Heft 3, 1891). This conclusion is confirmed by an examination of one of the Mount Hamilton negatives of July 20, 1890 (Moon's age, 4 days 3 hours), where the shadows are thrown toward the east, although the Sun was then somewhat too high (the terminator lay on the east wall of *Guttemberg*). In this the terracing east of crater F to crater A (*Peirce*, according to NEISON) is very easily made out, and the further course, at least in certain parts, can be readily followed.

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* Moreover, all of SCHMIDT'S ridges cannot be seen at any one age of the Moon.

According to MAEDLER (not in the *Mappa Selenographica*, but on his special chart of the eastern border of *Mare Crisium* in his work *Der Mond*), and also according to NEISON, craters A and B are connected with each other by a low ridge. This ridge is not given by SCHMIDT, and nothing of the sort is shown by the photograph. Crater *Eimmart*, *s*, (C in NEISON) shows plainly in the photograph a short prolongation of the walls on its southern side, and also a sinking of the southwest wall, of which no trace is found in SCHMIDT. The two small craters, discovered by OLBERS in Bremen in 1793, which lie east of No. 21 (*Promontorium Agarum*) can be detected by their illuminated eastern borders. A Mount Hamilton negative of August 31, 1890, in which the Sun is somewhat higher, proves clearly that they are craters. Regarding the other craters, SCHMIDT, in his *Beschreibung der* LOHRMANN'*schen Karte in* 25 *Sectionen*, p. 24, speaks as follows: "The plain (floor of *Mare Crisium*) is broken by only a few craters, of which *Picard* is the most prominent. A 6-inch refractor, however, will show in all about 30 craters, mostly of the smallest dimensions." These latter cannot be seen on the 4-fold enlargement, although some of them are visible when the original is examined with a high magnifying power. The bright transversal streaks in the eastern part of the *Mare Crisium*, which converge toward No. 19 (*Proclus*), are well seen (on the original) south of A, and between A and B. The straits (pass) east of crater *Picard*, *e*, show, on the photograph, only the small crater at the northern promontory, but this is very plainly marked. The bay which lies to the east does not appear on the photograph to be open to the north, as it is represented by SCHMIDT, but, on the contrary, it appears to be closed.

Let us now consider the *surroundings* of *Mare Crisium*, and let us take these in order from south to north. The ring-plain No. 4 (*Apollonius*) shows two craters in its western wall. These are placed too far south by SCHMIDT. Northeast of *Apollonius* lie two craters nearer together. The easternmost one (*f*) is drawn pretty correctly by MAEDLER, but the one to the west is represented as too small. On the photograph the two are of almost equal size. The great valley (*b*) east of *Apollonius*, with the southern encircling walled-plain, can be seen on the heliogravure with especial clearness, relief, and beauty. In west longitude +50° and north latitude +5°.5 (MAEDLER), that is, west of the ring-plain No. 14 (*Taruntius*), SCHMIDT, MAEDLER, and LOHRMANN depict a crater equally well marked, and of almost the same size as the two craters, nearer together, which lie southwest of it in longitude +53°, latitude +2°.5. MAEDLER'S longitudes are given to every 5°; according to him the longitude of the middle of both small craters is 53°.4. The easternmost one of these latter bears the letter *n* in SCHMIDT and in MAEDLER. On the original positive this crater is much less well marked (more indefinite), and is surrounded by bright ramparts, which hardly show on the heliogravure (west of the bright ridge, and in the line of the craters A and G). We must therefore conclude that this crater is, at present, of a different character from *n*, A, and G. On the Mount Hamilton negative of August 31, 1890, as well as on the plate of July 20, 1890 (with the shadows thrown to the east), it is somewhat better seen, yet it still stands in the same relation to *n*, A, and G. According to the photograph it seems to be of small depth, and to have walls which are but slightly above the plain of the *Mare Fœcunditatis.* The many craters of the drawing afford an interesting comparison in this respect. The very bright streak which runs northeast from *Proclus* is shown best by MAEDLER, whose representations of the relative brilliancies of the surroundings of *Mare Crisium* are in general more successful than any others. To the north of the very plainly marked crater in the east wall of the ring-plain No. 18 (*Macrobius*) there appears to be, in the northeast wall, not only an out-curving formation, as given by SCHMIDT, but a crater-like high valley, since the surrounding inner wall and its shadows can be seen (in the photograph). According to SCHMIDT, a long, high valley stretches northeast from *Macrobius*, the western terrace-like declivity of which is very plainly marked on the photograph by a long line of shadow. The crater which lies in this precipice (cliff) is also easily visible. To the southwest of *Macrobius*, *c*, SCHMIDT has a large ring-plain, which, however, appears to be a high plateau somewhat depressed in the middle. This shows on its northeast border a crater formation which is represented by SCHMIDT simply as a curvature of the inner wall. Here there is a long crateriform ravine extending toward the south, which is also laid down by SCHMIDT. West of the ravine a large, deep crater is plainly to be seen.

The declivity of the high mountain ranges on the north coast of the *Mare Crisium* toward the walled-plain *Cleomedes* (No. 15) is very clearly characterized on the heliogravure by a long bright band, and it appears to be extremely precipitous. In this place SCHMIDT has an interruption by a short cross-wall, which is not shown in the photograph on the cliff itself (though it can be seen in the plain to the north of it). In the south wall of *Cleomedes* the elongated crater (C, according to NEISON) has, toward the northeast, a bright appendage, which is the west wall of an enclosed tongue-like mountain formation. MAEDLER and NEISON have it erroneously as a second easterly crater. In the north, the manner in which crater A is situated in the wall of the long crater east of it is clearly exhibited. MAEDLER and NEISON erroneously give in this place three separated craters. LOHRMANN has represented this more correctly, and SCHMIDT'S map is the best of all, as the Mount Hamilton photograph of August 31, 1890, proves. Northeasterly from A a long, deep, mountain valley extends in a direction from the crater-plain

No. 16 (*Tralles*) to the walled-plain No. 14 (*Burckhardt*). This is entirely wanting in the maps of SCHMIDT and MAEDLER. On the other hand, SCHMIDT shows a similar hill-formation in a direction parallel to the east wall of *Cleomedes*. The representation by SCHMIDT of the manner in which the mountain walls spring from the interior plain at the north end of *Cleomedes* is especially unsatisfactory. To the south of the southwest corner of *Cleomedes* lies a large crater. The photograph shows a sudden drop of the plateau of this crater to the west, which is connected with the east wall of the great pass into the *Mare Crisium* lying to the south. SCHMIDT incorrectly represents this region as entirely level.

Northeast of *Tralles* and connected with it SCHMIDT shows an extended double crater formation like a figure-of-eight (*m*), which is wanting in MAEDLER and NEISON. The photograph exhibits this admirably, but it also shows that the southern end is not, as SCHMIDT gives it, open, but, on the contrary, closed by an elevation of the southern plateau, which here projects and presses in. On the southeast side of the walled-plain *Burckhardt* a long extended crater formation is joined to it, which is not given in NEISON. The southern end of this, as given by SCHMIDT, is not correctly limited, according to the photograph. Nearly half way between *Burckhardt* and *Geminus*, *d* (No. 13, *d*) the photograph shows a group of three craters. SCHMIDT has in this place three similar objects, each of which is, however, open on one side. The character of the elevations, as given by SCHMIDT, is particularly unsatisfactory in this neighborhood, also.

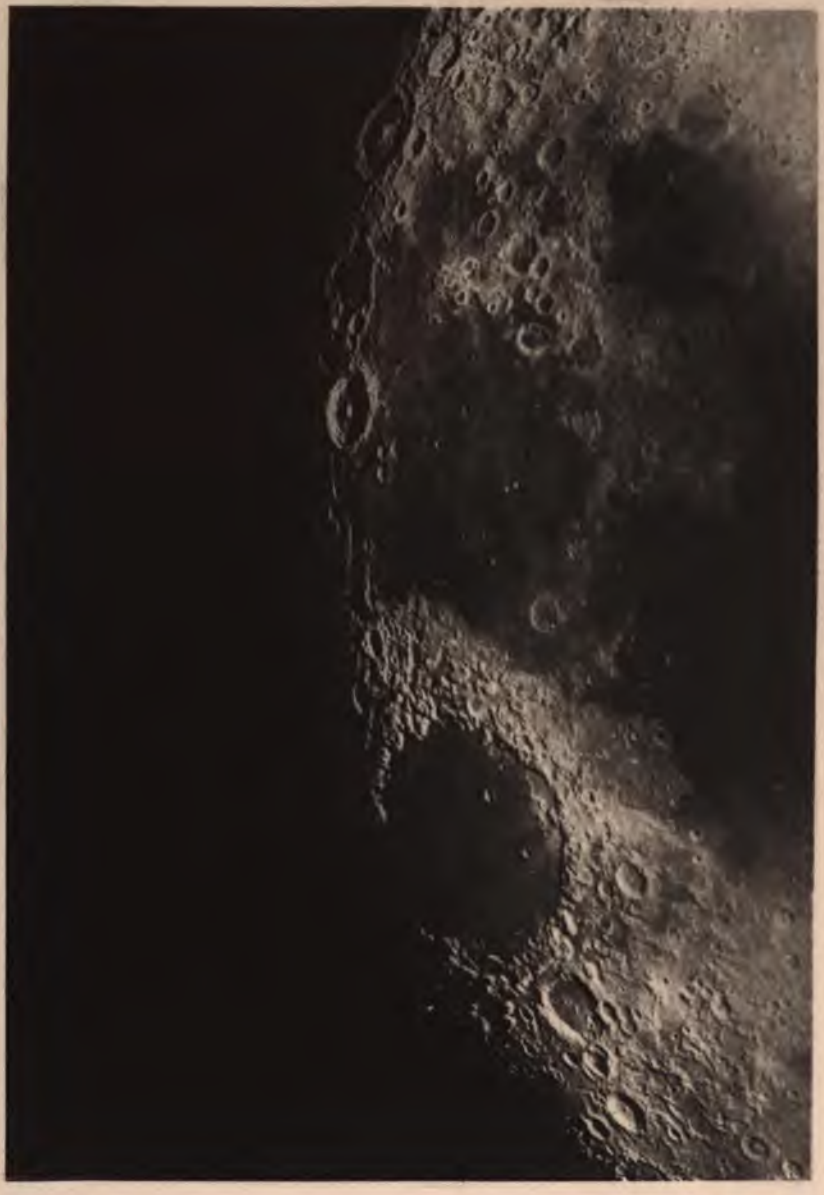
Between *Geminus*, *d*, and No. 17 (*Newcomb*, as it is called by NEISON) the photograph shows four plainly marked craters, which form a semi-circle, with its convex side toward the southwest. The most easterly one of these is not correctly placed by SCHMIDT. It should lie farther to the southeast, within the declivity of the mountain walls. Moreover, the relative dimensions of these four craters are not entirely correct in SCHMIDT. On the north wall of *Geminus*, in the direction toward the west wall of *Burckhardt*, the photograph shows a crater-like formation, which SCHMIDT does not give as such. Westerly from *Burckhardt* and *Geminus* the heliogravure exhibits a long, ravine-like formation extending toward the southwest, which recalls the great rill in *Petavius*. SCHMIDT has inserted this object, which was discovered by LOHRMANN in 1824, in his *Catalogue of Rills* (1866) as No. 8, and describes it as a valley-like rill. MAEDLER also drew this rill. Southerly from No. 22 (*Berzelius*), *d*, and northeasterly from *Geminus*, the photograph shows a double-crater formation, which lies on the southern declivity of a hill-plateau connected with *d*. SCHMIDT and MAEDLER do not give this object, but represent in its place a long crater valley on the eastern edge of the plateau, which is not visible in the photograph. The ring-plain *Berzelius* appears, according to the photograph, by no means so much closed on the south as it is drawn by

SCHMIDT. The east wall is there joined with the southern outliers, and the passage from the interior to the exterior seems to be without any steep declivities.

I have here given only a very few comparisons of the admirable Mount Hamilton Moon negative of August 23, 1888, with the published lunar charts, since the heliogravure speaks for itself. Such negatives offer an inexhaustible field for study, and they afford for all future time a true picture of nature, which must ever be of the highest value to the selenographer.

L. WEINEK.

Prague, 1891, December 4.



Mare Crisium.

ENLARGED TWO DIAMETERS FROM THE NEGATIVE
MADE AT THE LICK OBSERVATORY 1890 AUGUST 31
AT 14^{h} 27^{m} P.S.T.

PHOTOGRAPHIC ENLARGEMENT OF MARE CRISIUM AND THE REGIONS TO THE SOUTH.*

(See the heliogravure plate facing this page.)

This plate is a 2-fold photographic enlargement in the camera, by Professor S. W. BURNHAM, from the same excellent Mount Hamilton negative, taken 1890, August 31, which I have used for my 20-fold enlarged drawings of *Petavius*, *Vendelinus*, and *Langrenus*. The heliogravure (which I shall call H) is very sharp (as is to be expected from the small amplification), and is a successful reproduction of the plate from which it is copied. It was made by the k. u. k. Militär-geographisches Institut in Wien. Yet it is much inferior to the original negative (N), and to a glass contact-positive from it (P), which are in the collection at Prague, in respect of detail and of brilliancy.

The landscape extends from *Stevinus* in the south to *Messala* in the north. Near the upper right hand corner of the plate, the wall-plain *Fracastor* is to be seen; on the upper right hand border is *Theophilus*, and in the lower right hand corner *Franklin* and *Cepheus* are shown. *Mare Nectaris*, *Mare Fœcunditatis*, and the western half of *Mare Tranquillitatis* are also exhibited. In the southwestern region of the last-named sea, *Maskelyne* is shown on H, though far less satisfactorily than on P and N. The great rill-valley which breaks through the south wall of *Snellius* and extends to the middle of this walled-plain, the fine *Petavius* rill and the swelling interior of this crater, and the conspicuous rill-valley southwest of *Geminus* are clearly shown. The veins of mountain-summits and the bright streaks in *Mare Nectaris* (and especially those in *Mare Fœcunditatis*) are even better exhibited. But many of the latter formations, as well as corresponding features in *Mare Crisium*, are entirely lost in H, while they are plainly visible in P and N; for example, the long elevated ridge, which begins west of *Goclenius* in longitude +50°, then stretches in a north and south direction as far as the latitude of the south wall of *Langrenus*, next turns toward *Langrenus*, *f*, and finally extends once more in a meridional direction (having now the character of a terrace-like cliff bordering the *Mare Fœcunditatis* on the west) as far as the southern mountain region of *Mare Crisium*. The whole ridge can be traced in P and far less well in H; while the last-described portion is entirely lost in H.

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* Translated by EDWARD S. HOLDEN.

Other chapters of this book are devoted to a detailed discussion of my drawings of *Mare Crisium*, and the craters *Petavius*, *Vendelinus*, and *Langrenus;* and it is not necessary to do more in this place than to refer to these chapters. In this connection, however, it should be remarked that my 4-fold enlarged drawing of *Mare Crisium* was made from the Mount Hamilton negative of 1888, August 23. The two negatives have very similar illumination, and appear to be of the same excellence in their detail and in their fine relief.

Following, I refer to two very interesting objects in *Mare Nectaris* and in *Mare Fœcunditatis*, which I have not before described. The first object lies between *Theophilus* and the crater *Rosse*, nearer to the former, and consists of two dark spots, the southernmost of which is very clearly shown on H. In P and N it is easily to be seen that these dark areas surround two craters. The most southerly of the two is specially sharply defined, in spite of the fact that this region of the Moon is much over-exposed, lying, as it does, at a considerable distance from the terminator. These two craters are completely described in Dr. H. J. KLEIN'S *Führer am Sternenhimmel* (pp. 376–378), where a special chart of them and of their neighborhood is given.

The second object, referred to above, is the crater *Messier*, with its companion crater, *Messier*, A, which lies to the eastward, together with the surroundings of these craters in *Mare Fœcunditatis*. In the work of Dr. KLEIN, which I have just cited, pages 386–389 are devoted to a complete description, and to a detailed drawing of this region. The lettering given in Dr. KLEIN'S drawing I shall use here for the sake of clearness.

It is well known that MAEDLER described the two craters of *Messier* as exactly alike. His words are (*Der Mond*, p. 365): "*Messier* is a crater of 7° in brightness, two miles* in diameter, a closed ring-mountain, to the east of which lies another *exactly* like it in every respect. The diameter, the shape, the height and depth, the color of the interior (3°), as well as of the ring, indeed even the situation of several peaks on the ring—everything agrees so exactly, that we have here either a very remarkable sport of Chance, or the working of a law of Nature, as yet unknown to us. These twin craters become, moreover, still more remarkable on account of two streaks of light, which are *exactly alike*, straight as a string, sharply defined, 4½° in brightness, which extend eastward from the easternmost crater and gradually become less defined till they are lost. A dark zone, of 3° in brightness, is left between the two streaks, whose direction agrees pretty well with a line drawn through the centers of the two craters. The tail of a comet cannot be drawn sharper and more true to nature than it is here depicted." Further on MAEDLER says, in order to show how much attention he has paid to this region:

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* 1 German mile = 4.61 English miles.

"We can draw no conclusion as to the past history (of the *Messier* craters), but may give the assurance that we have observed them more than 300 times since 1829, on every occasion when this region was visible, and that we have always seen them as above described; and this, in spite of the fact that in a contour so sharply limited, the least alteration of the size, form, or brilliancy must have made itself manifest in a marked manner; and SCHROETER'S observation had directed our particular attention to this region."

A glance at the photographs, specially P and N, at once shows that the similarity of the two craters does not hold at the present time, whatever may have been the fact in the past. *Messier* appears as more extended (elliptical), with its longer axis in the direction of the so-called cometic tail, while *Messier*, A, on the other hand, is round. In order to reach a conclusion as to the real shape of both the craters, it is naturally necessary to take account of the effect of the libration and also of the relative levels of the two craters.

The heliogravure (H) shows a bright spot south of *Messier*, which is a defect in the plate. North and northeast of this spot are the craters called by Dr. KLEIN *a* (*b*, according to MAEDLER and SCHMIDT) and *f*. KLEIN remarks that, to the south of *Messier*, A, "at least four very small pits (*e*) or light spots" are to be found. P and N show in this place one definite object, which can scarcely be interpreted as other than a crater. On P and N, furthermore, the craters *a*, *b*, *d*, *e*, *f* can be well seen (*d* is the least obvious). *d* is, in all probability, a crater of insignificant depth and little brilliancy.

If we arrange the craters in the order of the difficulty of seeing them on the photographs, beginning with the most obvious, we have: *a*, *f*, *e* (south of *Messier*, A), *e* (south of *f*), *b*, and *d*. On page 389 Dr. KLEIN gives a description of a rill which was discovered on September 25, 1877, by M. GAUDIBERT. It has its origin between the craters *f* and *e*, then follows a smooth curve, convex toward the northwest, to the plateau *c*, and from thence goes in a meridional direction to the cometic tail of *Messier*, A. The part of this rill last described was first seen by M. GAUDIBERT on September 20, 1883; the whole object was observed by Herr KRIEGER on February 28, 1891; while Dr. KLEIN himself has not seen this rill at all. P, and particularly N, show the rill as above described very clearly; and exhibit, moreover, another branch, which extends from the plateau *c* to the crater *f*; and also a continuation along the line *e f*, which has a rill-like appearance, and which can be traced as far as the heights south of *Secchi* (*Taruntius*, B). These remarks on the details of this 2-fold enlargement will suffice. Nothing need be said of its beauty, nor of the admirable plastic and sharp relief of the western limb of the Moon, which it shows. As mere pictures such enlargements are very interesting. For most scientific uses, however, they need further amplification.

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PHOTOGRAPHIC ENLARGEMENT OF PETAVIUS, VENDELINUS, LANGRENUS, ETC.*

(See the heliogravure plate facing this page.)

This heliogravure (made by the New York Photogravure Company, from an enlargement in the camera by Mr. A. L. COLTON) represents one of the 7-fold enlargements made at the Lick Observatory on the scale of MAEDLER'S chart. Professor HOLDEN has sent to me a copy of the *dia-positive* from which the heliogravure was copied. This glass positive shows a fine relief, great brilliancy, and a relatively fine grain. Unfortunately some of these good qualities are not entirely preserved in the reproduction, though the plate (which is an untouched copy of the original) must be considered as, in general, very successful. The grain of the original plate has almost disappeared in the heliogravure; where the individual particles have, so to say, melted into each other to produce an almost structureless background. In consequence of this the image possesses a pleasing smooth character, but it has lost considerably in light-effect and in richness of detail.

The plate represents chiefly the three great walled-plains, *Petavius*, *Vendelinus*, and *Langrenus*, with evening-illumination, from the same excellent negative (1890, August 31, 14^h 27^m, P. S. T.) which I have used as a basis for my drawings of the same craters, 20-fold enlarged. My drawings of *Vendelinus* and *Langrenus* were so made that the corresponding plates given in this volume join on to each other precisely. My drawing of *Petavius* does not, however, accurately join that of *Vendelinus*. The heliogravure under consideration serves, then, as a supplement to my drawings of these three craters, and shows that only a very narrow strip between the two craters last named has been omitted.

The larger ring-plains, which are shown on the plate, are, proceeding from the south toward the north:—*Furnerius* (not completely shown), *Stevinus*, *Reichenbach*, *Snellius*, *Borda*, *Wrottesley*, *Santbech*, *Cook*, *Colombo*, *Magelhaens*, *Goclenius*, and *Guttemberg* (not well defined). The *Mare Fœcunditatis* extends from the south, where the small ring-plain *Biot* is situated, as far as the twin-craters *Messier*

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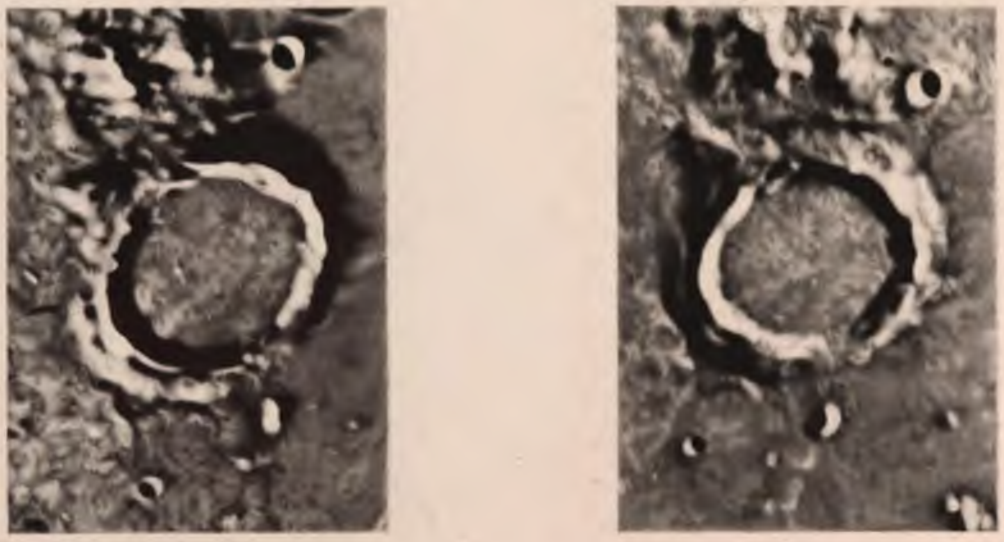
* Translated by EDWARD S. HOLDEN.

(which are, however, not shown on the plate). Those parts of the field which lie farther from the terminator are better shown in the plate of *Mare Crisium*, 2-fold enlarged, as is natural. For a discussion of the areas of the lunar surface, which are exhibited in this plate, I refer to the text which accompanies the two plates of *Mare Crisium* (enlarged 2-fold in the camera, and 4-fold in my drawing), and to the sections descriptive of my drawings of the single craters *Petavius*, *Vendelinus*, and *Langrenus*, 20-fold enlarged.

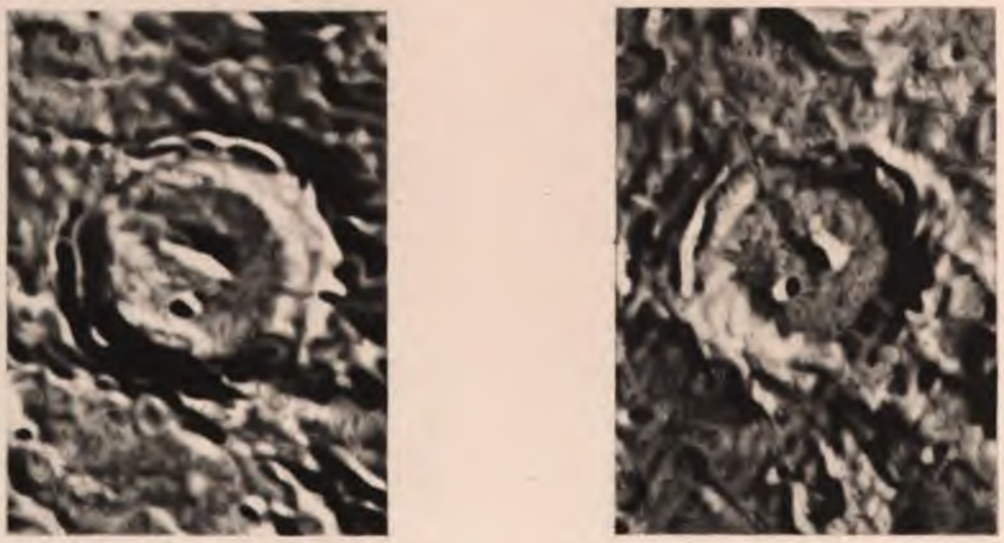
I II



Archimedes
1888 August 15

Archimedes
1888 August 27

III IV



Arzachel
1888 August 15.

Arzachel
1888 August 27.

DRAWINGS BY PROFESSOR DR. L. WEINEK, ENLARGED TEN-FOLD
FROM NEGATIVES TAKEN AT THE LICK OBSERVATORY ON AUGUST 15, 1888
(I AND III) AND ON AUGUST 27, 1888 (II AND IV).

DRAWINGS OF ARCHIMEDES.*

(See heliogravure plate facing this page, figures I and II.)

In November, 1889, Professor EDWARD S. HOLDEN kindly made the proposal to send to Prague a series of the best negatives of the Moon, taken with the 36-inch refractor of the Lick Observatory, in order that they might serve as a basis for my drawings of lunar craters and lunar landscapes made at the telescope, as well as to furnish subjects for special studies of the Moon's surface. I was all the more eager to entertain such a proposition, because the Prague Observatory is possessed of only a 6-inch telescope on a very inconvenient mounting, and because an opportunity was offered to take part in the magnificent results of the—at present—largest instrument in the world.

Up to this time I had made fifty-four lunar drawings at the telescope, and I was justified, by reason of considerable practice of eye and hand, in taking up this new labor.

Since the beginning of the year 1890, Professor HOLDEN has sent to Prague continuously a large number of plates for the different days of a lunation, and I am greatly indebted to him for creating an incentive to do this work, as well as for the valuable donation of these beautiful plates to the Prague Observatory from the Lick Observatory.

For the purpose in view I had built at Dresden a suitable apparatus before beginning the task. In this the photographic plate is viewed by transmitted light by means of two eye-pieces of 41.15 and 25.20 *millimeters* (equivalent) focus. (Linear enlargement = 7.8 and 12.1 for my distinct vision of 28 *centimeters.*) The holder or stand of the eye-pieces possessed a double motion in two coördinate directions normal to each other; it admitted of a ready and rapid adjustment of the portion of the Moon viewed, and kept the chosen lens at a constant distance from the plate. The illumination of the latter may be obtained by daylight or by means of a lamp; in the case of the former a parabolic reflector may be so set or turned as to furnish the desired degree of light. For drawing, diffused daylight is used, by inserting a dull ground glass between the plate and the reflecting mirror. The window at the left hand of the draughtsman throws light at the same time on the small drawing-board which holds the paper. A handy little drawing-table attached to the lower part of the apparatus, completes the outfit. That the person engaged in viewing or drawing may not become too easily fatigued, the plate with the mirror may be turned backward and set at will to any desired angle. The apparatus is arranged for large plates as well as for very small ones.

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* Translated by OTTO VON GELDERN, and printed in the *Publications of the Astronomical Society of the Pacific*, volume III, page 333, to accompany two *lithographic* charts of this crater.

Since every direct photographic enlargement presents numerous defects, and will be found inferior to the original, particularly in strength and intensity, it was not a superfluous undertaking to prepare enlarged drawings or tintings from the original plates—drawings that were to be made in this case with the greatest exactness and absolute truth as to strength and clearness—for the reason that work done in this manner may be continued at any time, and can be constantly controlled and improved upon.

In this particular *two* methods were available; the first, by having very faint photographic enlargements of certain particularly interesting portions of the lunar surface thrown upon suitable paper, and by retouching them subsequently to the full intensity of the original; and the second, by discarding photographic aid altogether and projecting a mathematically accurate enlargement to any desired scale, by means of suitable instruments, directly upon the best white drawing paper, upon which the representation is then newly developed and entirely built up.

In the first, or photographic method, which I used in making a 4-fold enlargement of *Mare Crisium*, from *Apollonius* in the south to *Geminus* in the north, taken from the beautiful Lick-negative of August 23, 1888, a work requiring 34¾ hours, I found it very unfavorable that the so-called salt paper (salz-papier), which is commonly in use in photographic coloring, is of so hygroscopic a nature that it requires the most careful and painstaking drying, at a considerable expense of time; and again, I have found that every photographic paper will lose in whiteness by reason of the chemical process it has to undergo, and in consequence will not admit of showing the lighter portions of the Moon with sufficient brightness. It was principally for the latter reason that I soon adopted the second method. Since an exact tracing of contours was unavoidable, and since I found that even the most transparent papers with *millimeter* graduation were unsatisfactory, I had glass scales made containing precise divisions into square *millimeters*. These, as well as the above described drawing apparatus, were made by the mechanician HEYDE, of Dresden, who, after a few trials, succeeded in etching these scales. Such a scale is now laid, with its etched side down, upon the plate, and held there by means of two springs at its opposite ends; that part of the lunar surface which it is desired to enlarge is followed in the smaller squares on the glass, and reproduced in similar squares previously drawn on the paper to any required degree of enlargement. In this manner the originals of the two heliogravure copies accompanying this paper, of the magnificent ring-plain of *Archimedes* were drawn, magnified ten diameters.

The picture on the left belongs to the Lick-negative of August 15, 1888 (age of the Moon, 8 days), and required for its final and finished completion in tints 44¾ working hours; while the one on the right is from an exposure taken at the Lick Observatory on the 27th of August, 1888 (age of the Moon, 20 days), and required a working-time of 43 hours. Each is of a size of 5x7 *centimeters.*

Let us now proceed to the scientific discussion of these drawings. In what follows the one on the left will be designated as I, that on the right II.

At first glance it is recognized that *Archimedes* appears somewhat larger on I than on II, although both drawings were magnified from the originals exactly ten times. From this it must be concluded that the lunar diameter of the photograph taken on the 15th of August, 1888, must have been larger than on the one taken August 27, 1888. And indeed we find that, measuring in the line of the zero meridian (direction from the eastern wall of *Autolycus* to the west wall of *Ptolemy*) the diameter is 130.0 *millimeters* for the first named plate, while for the second it is only 119.7 *millimeters.* This is further explained by the fact that I was taken near the time of the Moon's perigee (which took place on August 14th, at 0^h, Greenwich mean time), whereas II was obtained near the apogee of the Moon (occurring on August 28th, at 1^h, Greenwich mean time). If, for an approximation, the corrections for refraction, parallax, and libration be left unconsidered, the arithmetical mean of the dimensions of I and II may be looked upon as that corresponding to the mean distance of the Moon from the earth, which, as well known, was used in the large lunar charts of 1 *meter* by LOHRMANN and MAEDLER, and the 2-*meter* chart made by SCHMIDT. Since the latter is based upon observations extending through a period of over thirty years, and is the most detailed, let us adopt it for the purpose of making our comparisons. *Archimedes* is shown upon Section IV of the same. As far as the effects of libration are specially concerned, a simple reflection will show that on account of the juxtaposition of *Archimedes* to the central meridian, it is principally the libration in latitude that need be considered. Since the center of the Moon was 4° above the ecliptic on the 15th of August, and on the 27th, 5° below it, the first exposure would necessarily show more of the southerly portions, and the second more of the northerly parts of the lunar surface. But since *Archimedes* is situated in about 30° selenographic latitude in the northern hemisphere, it follows that this walled-plain must lie nearer to the visible edge of the Moon on I than upon II, which is confirmed by comparing the two photographs. For this reason the meridional dimensions of I must appear perspectively shortened and those of II perspectively lengthened, when compared with those that occur under a mean geocentric libration in latitude (the Moon's center being in the ecliptic); and in our case this must be so in nearly equal amounts, so that, roughly speaking, we may also consider the mean of I and II as free from all libratory effects.

In order to make this subject intelligible to the reader without the aid of a contour drawing from I or II, and without adopting a nomenclature of figures or letters for the numerous objects of each picture; and in order to permit a most careful comparison with SCHMIDT'S chart, it will be well to characterize the single objects by means of polar-coördinates referred to some easily determined initial point. As such the center of the ring-plain might be taken, provided that its periphery were sufficiently regular for that purpose. But this is not the case. I have therefore joined the centers of the two craters, located southeast and northwest from *Archimedes* respectively, crater A (shown in the picture in the upper right hand corner) and C (at the lower left hand), by drawing a straight line from one to the other; this line was bisected, and the point of bisection, which is nearly in the middle of *Archimedes*, was adopted as the initial point (O) of the coördinates. By the projection of this line AOC, as well as by drawing the lunar meridian passing through O upon SCHMIDT'S chart, the angle between the line OA and the direction O-South was found to be 51°. This angle properly laid off from AC on I and II, determines, upon each picture, the position of the meridian through O, and defines thus the cardinal points, north, south, east, and west for the landscape. If, furthermore, the angle between O-North and O-Object, measured from the north around to the east, be called the position-angle (p) of the object, the location of the latter will be absolutely fixed by this angle and the linear distance (d) of the object from O. It is also to be noted that when the lunar meridian is traced upon both pictures, this line appears upon II as though it were turned 15° toward the east in the upper part; this corresponds to the position of the line of the limit of light to the vertical edge of the plate in the exposures. The latter direction, however, was the necessary guide for the orientation of the enlarged drawing.

By comparing the distance AC upon I and II with the same distance upon SCHMIDT'S chart, we obtain at once the scale of my 10-fold enlargements, presuming that it is correctly given on the former. SCHMIDT gives AC = 83.5 (MAEDLER 43.0), on I it equals 61.0, and on II 57.0 *millimeters*. Since it is necessary to take the average of I and II, in order to reduce the Moon to mean distance, the dimensions of the mean of both drawings are smaller than SCHMIDT'S in the proportion of 59.0 to 83.5. Every linear value of SCHMIDT'S chart, therefore, if multiplied by 0.7 will give very nearly the corresponding dimensions in the scale of my enlargements. It follows that I and II correspond to a lunar chart having a diameter of 1.4 *meters*, which is nearly a mean between that of MAEDLER and that of SCHMIDT.

Since on the latter 1 *mm.* = 0″.95687 = 1.7832 *kilometers*, it is seen that upon I and II, 1 *mm.* = 1″.367 = 2.547 *kilometers*. A proof of this relation between linear and angular measure may likewise be deduced from the photographic focus of the Lick refractor. This taken at 570.2 inches = 14.48295 *meters*, will make the angle corresponding to 1 *millimeter* on the plate equal to 14.2419 seconds of arc, and increasing ten times, 1 *mm.* becomes equal to 1″.4242. We may therefore accept that 1 *mm.* = 1″.4 in these drawings.

In the following table the most notable objects upon I and II have been identified upon SCHMIDT's map by setting off their position-angles and distances. In order to enable one to compare the latter with I and II, the dimensions from the SCHMIDT chart are multiplied by 0.7, those of I by $\frac{59}{61}$, and those of II by $\frac{59}{57}$, and the values so obtained have been designated as reduced distances. That which has been found at variance with SCHMIDT may be seen in the annotations to each object at the foot of the table.

TABLE OF OBJECTS.—ARCHIMEDES.

Quadrant...	Object No...	SCHMIDT.		I.		II.		SCH.	I.	II.	General Description and Position of Objects.
		p	*d*	*p*	*d*	*p*	*d*	Reduced *d*			
		°	mm.	°	mm.	°	mm.	mm.	mm.	mm.	
N.E.	1	7	43.5	6½	27.1	5	25.5	30.4	26.2	26.4	Small crater northeasterly of mountain E.
	2	...	...	....	...	14–61	11–12	...	...	...	Northeast wall on interior.
	3	...	...	70	12.0	...	...	...	11.8	...	Inner boundary of northeast wall.
S.E.	4	120	50.5	....	...	120	33.7	35.3	...	34.9	Crater-like object east of crater A.
	5	129	41.8	129	30.5	129	28.5	29.3	29.5	29.5	Crater A.
	6	...	...	....	...	132	17.1	...	...	17.7	Crater-like object on southeast wall.
	7	141	40.0	....	...	140	29.8	28.0	...	30.8	Object southwesterly of crater A. Defect in plate?
	8	156	20.5	156	14.7	156	14.4	14.3	14.2	14.9	Southerly mountain crest on exterior.
	9	...	...	....	...	162	24.3	...	...	25.2	Defect in plate?
	10	...	...	165	31.0	166	31.2	...	30.0	32.3	Object in mountain mass south of *Archimedes.*
S.W.	11	...	...	183	32.0	183	30.7	...	31.0	31.8	Object in the same mountain mass.
	12	210	50.0	....	...	...	...	35.0	...	...	Rill χ, southwesterly of *Archimedes.*
	13	...	...	210–232	8	...	...	...	7.9	...	Southwesterly wall on interior.
	14	...	...	235	5.1	...	...	...	4.9	...	Bright spot in interior. Fault in plate.
	15	237	20.0	236	15.5	...	...	14.0	15.0	...	Transverse cañon in southwest wall.
	16	...	...	237	24.7	...	...	...	23.9	...	Ridge southwest of *Archimedes.* Fault in plate?
	17	247	39.3	249	24.0	...	...	27.5	23.2	...	Terraced declivity, west of *Archimedes.*
	18	...	...	250	17.6	...	...	...	17.0	...	Yoke-like connection between westerly wall on exterior and interior.
N.W.	19	273	37.0	....	...	277	21.0	25.9	...	21.7	Annular ridge west of *Archimedes.*
	20	281	30.0	281	21.2	...	...	21.0	20.5	...	Crater-like object on west outer wall.
	21	...	...	....	...	304	34.7	...	...	35.9	Crater pit. Defect in plate?
	22	309	41.8	309	30.5	309	28.5	29.3	29.5	29.5	Crater C.
	23	332	36.4	333	25.7	331	26.1	25.5	24.9	27.0	Crater *d.*

Remarks.

1. This little crater, shown by SCHMIDT, northeast of mountain E, with a diameter of about 2.5 *kilometers*, appears bright on I (like crater *d*, northwest of E) and may perhaps be identical with the little dark speck in the given position on II. There is a better agreement of *p* and *d* in I than in II; it is necessary to observe that on account of libration the first distance is to be increased and the second decreased in order to obtain a reduction to mean libration.

2. The interior northeast wall shows in this area two extensive depressions on II, the northerly having a crater-like appearance; while SCHMIDT has this inner wall entirely separated from the outer, without showing any transverse yoke or saddle.

3. At this point we notice upon I a light finger-shaped appendage (buttress), of the extent of 1½ *mm.*, by which the inner wall projects into the floor of *Archimedes.* SCHMIDT has nothing similar.

4. This object, east of crater A, appears on II like a crater-pit, and agrees with the most northerly of the small craters there depicted by SCHMIDT.

5. The northwest edge of crater A is not sharply defined upon II. While the diameter of this crater, measured normal to the line of the Sun's direction, is nearly 4 *mm.* on both I and II, this is no longer the case if measured in the direction of the Sun, for in that case it becomes 4.7 (reduced 4.5) on I, and 5.2 (reduced 5.4) on II, whereby an uncertainty in the position of the adopted initial point of the coördinates of 0.25 *mm.* is caused.

6. On the southeast wall we have here according to II a nearly circular shallow depression of about 1½ *mm.* diameter, which shows similar characteristics to the object described under (4). SCHMIDT has no indication of it, whereas the little crater shown on his chart on the southeast wall, with $p = 109°$, $d = 25.4$ *mm.*, cannot be recognized on II.

7. This object on II looks like a crater with a light floor, but it is possible that it may be a fault in the plate, for spots of similar extent, rotundity, and intensity appear quite frequently upon the positive plate, where their size amounts to 0.1 *mm.* only, in places where such craters do not occur at all. It may be mentioned that this spot agrees pretty well with the end of the southwesterly valley joining to A as shown by SCHMIDT.

8. At this point the course of the outer crest line of the southwest wall agrees on I and II, but differs from SCHMIDT.

9. Appears to be a faulty small speck in plate II. SCHMIDT shows at this point no crater of any kind.

10. Here we notice upon II, in the mountain mass south of *Archimedes*, a depressed elliptical plain of 4 *mm.* in extent, containing a central elevation. The

position of the latter is designated by the given values of *p* and *d*. The same elevation is also found on I. The difference in *d* is fully explained by the effect of libration. This object, having all the *appearance* of a crater-like plateau on a high mountain range, not unlike the basin of a mountain lake, is shown neither by SCHMIDT, MAEDLER, LOHRMANN, nor NEISON.

11. This object looks on I like a crater formation, which it cannot be, however, considering the shadow cast. It represents rather an elevation with an easterly shadow, as readily detected upon II. Analogous illusions are apparent in several other objects of this plate, south of the one mentioned, but which have not been shown here.

12. Of this known rill nothing certain is recognized on I and II. The cause may lie in the conditions of exposure of the plates.

13. This part of the southwest wall shows on I very sharply notched configurations, which are not found on II. This may lead us to the conclusion that these notches lie deeper than the crest, which is confirmed by SCHMIDT'S drawing of the southwest wall.

14. At this point we notice upon I in the interior of *Archimedes* a bright spot with an apparent easterly shadow. If this object of the plate has a real existence on the Moon it would be a most interesting one, for MAEDLER ("The Moon" . . .) says: "We further remark that MAYER'S small chart of the Moon has a bright spot in *Archimedes*, which seems to designate a central mountain. Such an one, however, is known with absolute certainty not to exist here. He probably saw the light central stripe very indistinctly, and took it to be a central elevation." As we had no additional photographic plate of the same evening in Prague on hand, the decision of this question was left to Professor HOLDEN, who, after a most careful examination of the plates preserved at the Lick Observatory, expressed himself as against the real existence of this bright spot.

15. This transverse cañon in the southwest wall shown by SCHMIDT is clearly identified on I.

16. This position characterizes on I the center of a bright ridge casting a shadow, situated southwesterly of *Archimedes*, extending about 7 or 8 *kilometers* nearly in the direction of the meridian, which object is entirely missing on SCHMIDT'S chart, which indicates there a smooth plain. If this be not again a fault of the photographic plate similar to object 14 (which, however, is hardly probable), the reality of this ridge should become a particularly interesting fact. Nothing certain is discernible thereof on II.

17. This object seen upon I, the center of which is located by *p* and *d*, makes the impression of a terraced declivity casting a shadow of about 10 *kilometers*, west of *Archimedes*, and may be identical with the elevation shown by SCHMIDT, extending from northeast to southwest.

18. At this point will be noticed a yoke-like connection between the exterior and interior walls of *Archimedes* in the west. On both sides of the same there are noticeable rifts or ravines of considerable depth. SCHMIDT has no indication of this.

19. Upon SCHMIDT'S chart this annular ridge is shown in the shape of a triangle. On I it is nearer like an oval lying in the direction of the meridian. Position-angle and distance of the centers do not agree with sufficient accuracy.

20. This object seems to represent on I a crater-like depression, but does not appear as such on SCHMIDT'S representation.

21. On II there is seen at this point something that looks like a sort of a crater-pit of small size, but this object is just as likely to be a defect in the photographic plate.

22. This crater, designated by SCHMIDT as C, shows upon I an elevated appendage or buttress on the east toward the mountain E, and on II it shows to the north and almost adjoining it a shallow pit. These are not given by SCHMIDT.

23. This crater, which SCHMIDT refers to as *d*, appears on I as a bright spot, but upon II as a real crater. The difference in distance between I and II is accounted for by the effect of libration. It might be presumed, judging from the diverse character as indicated by the photographic plates, that only the eastern wall of this crater is of a precipitous nature; while the western wall has a more gentle declivity, which would throw a deep easterly shadow only at a lower position of the Sun. (Compare, however, the corresponding remarks upon *d* below; and in the description of *Arzachel.*)

Mountain E.—This is interesting on account of the difference in shape on I and II. From it a long ridge reaches toward the southwest, which does not, however, pass as uniformly as SCHMIDT has it. Particularly interesting is the dark crossing of the same, shown on both drawings east of the crater *d*.

Concerning the interior of *Archimedes* it is evident that both photographs do not at all lend it the appearance of the "mirror-like smoothness" of MAEDLER'S plain. In considering its numerous and diverse photographic details, it is, of course, to be observed that we are not able to separate those which are due to the inequalities of the bottom, from those that find their origin in faults of the plate and in the finer gradations of the sensitive film, so long as there are not at least two plates taken consecutively on hand for comparison. For this reason a discussion of the interior details of *Archimedes* must here be omitted entirely. It may only be mentioned that the well-known lighter zones of the floor are quite visible, but that of the finer craters, shown by SCHMIDT and others, nothing is discernible in the interior.

The whole comparison of these photographic representations with SCHMIDT'S chart confirms again the excellence of the latter, but it shows, too, that it may be improved upon.

It has also been of great interest to me to compare I and II under the same conditions of light with a view through the 6-inch STEINHEIL refractor of the Prague Observatory. II was compared on the 31st of March, 1891, at 16½ʰ Prague mean time, I on April 17, 1891, at 8½ʰ Prague mean time, with the celestial object. Although at both times the air was rather unsteady and not very clear, so that a magnifying power of only 150 seemed advisable, still it was readily proven to me that the photograph did not represent everything visible. For instance, clear and easily discernible tracings of terraces, on a brightly illuminated background were lost entirely, while in the lesser shaded parts a plentiful and just as easily distinguished detail was lacking altogether. It is possible to explain this only by assuming that the adopted mean period of exposure for the plate, which would furnish the best *average* picture, over-exposes the bright walls of *Archimedes*, and that thus the dark terrace lines thereon are obliterated, as a result of the effect of diffraction of the surrounding light (compare the photographic representation of a narrow lightning-rod on a background of light clouds, which by exceeding a certain exposure will disappear entirely from the picture), and, on the other hand, shaded portions of the wall are under-exposed in the same manner. It must also be mentioned here that on the 17th of April, 1891, the crater *d* showed in its interior *another* shadow, whereas the same is entirely lacking on I. In addition to all this we must admit that numerous photographic details were *not* discernible with the telescope.

From the foregoing, the conclusion is justified that photographic representations of the Moon, as constantly improved upon and now approaching a degree of completeness never before attempted, as at the Lick Observatory, furnish a most valuable aid to optical observation, and will, considering the diversity in the chemical and optical *albedo* of the lunar surface, become the means of materially supplementing it. But it is to be remembered that *one* photograph alone will not give us an absolutely true representation of the Moon, meaning a representation of *everything* visible; for with a certain period of exposure some parts will be sure to be over- and others under-exposed. It is only by taking a series of consecutive photographs of varying exposures, which should be confined rather to very small lunar areas, that we can finally hope to obtain a copy true to nature. In the same manner in which we succeed in photographing the dark solar spots on the bright face of the sun, we should also be enabled to obtain the dark terraced lines on the lighter walls, heretofore referred to, or the fine black rills surrounded by bright light, if the exposure of the plate be properly reduced. The final decision in this matter, however, will depend upon experiment. Although a photographic representation of the Moon, in spite of the most excellent results of the Lick Observatory, leaves much to be desired in point of strength and clearness, as is particularly apparent in studying the greater enlargements, it yet furnishes us a wonderfully beautiful relief of considerable extent, which can *never* be retained and depicted with equal truth to nature by the most skillful draughtsman, on account of the great number of visible objects and the rapid change of lunar shadows; and at the same time it gives an astonishingly accurate detail of individual portions, which, for the control and revision of present lunar charts, becomes of the *utmost* value to the selenographer.

L. WEINEK.

Prague, July 6, 1891.

With reference to the heliographic reproduction of *Archimedes*, it is to be remembered that although it is exquisite in appearance, the finer shades on the bright walls, as well as the tones where there is a transition from darker to lighter portions, or conversely, are still given incompletely and do not fully represent the delicacy of the original.

DRAWINGS OF ARZACHEL.*

(See the preceding heliogravure plate, figures III and IV.)

The 10-fold enlargements III and IV were obtained in the same way as those for *Archimedes*. Figure III absorbed 42¾, and IV, 49¼ hours of actual work.

In order to discuss the drawings of *Arzachel* in the same way as those of *Archimedes*, it will again be necessary to choose an origin of coördinates, O, within the walled-plain. It appears to be most advantageous to place the origin at the center of the deep crater A (Schmidt, Maedler), which lies near the middle of *Arzachel*. In order to fix the meridian through O, this latter point should be joined with the middle of a second round crater, somewhat smaller than A, which lies on the southwestern outer wall of the ring-plain *Alphonsus*, and the relation of this line to the meridian must be fixed by the data given on Schmidt's map, Section VIII. The crater last referred to (called *d* by Neison) is shown in III to the right and below *Arzachel*, and in IV almost immediately below and in the middle of the figure. As is well known, the great lunar chart of Schmidt was constructed by taking as a basis the positions determined by Lohrmann, and the finer details were then inserted, preserving the adopted scale. Schmidt's chart, therefore, includes all the errors of Lohrmann's map, as well as those which, in the nature of the case, must arise in this method of drawing. As, however, the small crater last named lies close on the border of a larger valley, surrounded by mountains (ring-plain), its position, as given by Schmidt, can be assumed as essentially correct, at least so far as relative proportions are concerned. The meridian through O lies, according to Schmidt, in the northern parts of figures III and IV (that is, in the lower portions of the plate), about 15° east (to the right) of the line, joining the two small craters in question.

It may be here remarked that very considerable differences exist between Schmidt (Lohrmann) and Maedler in this region of the Moon. The line just described, joining the two small craters, makes in Maedler's *Mappa Selenographica* an angle of 26° with the meridian instead of one of 15°. Moreover, Maedler's position of the middle of the crater A is, east longitude —2° 14′; south latitude

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*Translated by Edward S. Holden.

—18° 4′ (see MAEDLER, *Der Mond*, p. 304); while these positions from LOHRMANN'S chart are, east longitude —1°.19; south latitude —17°.89. While the latitudes agree very well, the longitudes differ by a whole degree. In MAEDLER'S map, also, the meridian of longitude —5° passes almost exactly through the middle of *Thebit*, while the same meridian, according to LOHRMANN, is drawn to the east of that crater. If, again, we measure the angles which have their vertex at A, and which are included between lines joining A and the second small crater named above, and joining A and a third crater of the same size which lies west of *Arzachel* (in III this crater is on the left hand edge of the figure, about 13 *mm.* from the lower border), we find these angles to be 82° according to SCHMIDT (LOHRMANN), 53° according to MAEDLER, and 69° according to figure III. The last number requires, however, to be somewhat diminished on account of libration, so that we may regard the photographic value as lying midway between the other two. These examples are sufficient to exhibit the degree of agreement of the chart of SCHMIDT with the photographs, and to show that it must not be expected to be exact. On the other hand, a precise agreement should exist between III and IV, as in fact is the case.

In order to find identical objects on III and IV as easily as may be, it will be the simplest to imagine the dark points on III as bright on IV, and conversely; or to regard one picture as a positive while the other is considered as a negative. The agreement of the two figures is then remarkable. At the first glance it appears that III is extended in the direction of the meridian, while IV, on the other hand, appears to be compressed. This is fully explained by the effect of the libration in latitude previously spoken of in connection with the *Archimedes* drawings, except that this operates in the contrary way since *Arzachel* lies in *south* latitude. I is shortened, III is extended; II is lengthened, IV is compressed; although I and III as well as II and IV correspond to the same moment of observation, the first to August 15, 1888, the second to August 27, 1888.*

With this preface, we may proceed to the comparison of the principal objects on III and IV with SCHMIDT'S chart. For this purpose each object in the following table is designated, as in the case of *Archimedes*, by its position-angle and distance from the origin of coördinates. The reduced distances can be calculated by the use of the same factors employed with *Archimedes*, although the factor of reduction 0.7 for SCHMIDT is not entirely satisfactory for *Arzachel*. This may arise either from an erroneous length AC on SCHMIDT'S *Archimedes* drawing, or from other errors of the position on his drawing of *Arzachel*.

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*On the Moon-negatives taken in 1888, by Professor BURNHAM, there is no record of the hour and minute of exposure-time.

ARZACHEL.

Quadrant...	Object No...	SCHMIDT.		III.		IV.		S.	III.	IV.	General Description.
		p	*d*	*p*	*d*	*p*	*d*				
N.E.	1	14	49.1	....	....	....	....	34.4	....	....	Crater on the inner S.W. edge of *Alphonsus*.
	2	25	46.0	....	....	29	29.5	32.2	....	30.5	Crater *a* (MAEDLER), east of No. 1.
	3	....	...	36	10.5-15.5	47	9.5-14.0	...	10.2-15.0	9.8-14.5	Object on the N.E. inner wall of *Arzachel*.
	4	....	...	63	11.5-16.5	70	11.0-15.0	...	11.1-16.0	11.4-15.5	Object on the N.E. inner wall of *Arzachel*.
	5	59	31.7	61.5	19.0	71	16.5	22.2	18.4	17.1	Crater *b* (SCHMIDT, MAEDLER) on the N.E. crest.
	6	84	38.0	....	....	....	....	26.6	....	....	Crater S.E. of *b*, on the eastern outer wall.
S.E.	7	106–140	35.0	115–145	22.3	110–143	20.2	24.5	21.6	20.9	Large valley *e* (NEISON) on the S.E. crest.
	8	109	19.2	....	....	111	12.5	13.4	....	12.9	Small dark spot in the S.E. inner portion of *Arzachel*. A crater.
	9	131	59.7	....	....	132	39.0	41.8	....	40.4	Crater north of *Thebit*.
S.W.	10	....	...	192–208	18.7	....	....	...	18.1	....	Valley on the S.W. crest of *Arzachel*.
	11	184	61.5	....	....	195	35.3	43.1	....	36.5	East wall of the ring-plain *e* (SCHMIDT, MAEDLER) N. of *Purbach*.
	12	....	...	....	....	199	16.0	...	....	16.6	Dark spot on the S.W. crest. Defect in the plate?
	13	230	22.3	237	16.5	236	15.1	15.6	16.0	15.6	Curvature in the S.W. outer crest.
	14	252	15.2	....	....	255	11.2	10.6	....	11.6	Crater-like depression on the west inner wall.
N.W.	15	263	35.3	276	26.7	....	....	24.7	25.8	....	Crater west of *Arzachel*, N.E. of ring-plain *c* (SCHMIDT, MAEDLER).
	16	....	...	282	14.5	....	....	...	14.0	....	Crater-like formation on the west outer wall.
	17	286	37.0	299	28.5	299	25.5	25.9	27.6	26.4	Large crater-like formation north of No. 15.
	18	295	20.8	300	14.5	302	13.7	14.6	14.0	14.2	Projection in the N.W. crest.
	19	322	44.4	....	....	326	28.0	31.1	....	29.0	Rill or valley west of No. 21.
	20	330	6.5	337	5.1	....	....	4.5	4.9	....	Serpentine rill in the N.W. interior.
	21	345	43.1	345	28.7	345	24.7	30.2	27.8	25.6	Crater on the S.W. outer wall of the plain-ring *d* (NEISON).

Remarks.

1. In this place SCHMIDT has drawn a small crater, forming the end of a crater-rill which originates in the north wall of *Arzachel*, and which debouches in the southwest border of the interior of *Alphonsus*. Although the illumination does not appear to be unfavorable, this is not shown as such on figure IV. The light area in $p = 18°$, $d = 28.6$ *mm.* should be a part of its east wall. North of this, the southernmost of the known dark spots in *Alphonsus* is to be seen. Between

$p = 0°$ and $p = 16°$, IV shows the southwest wall of *Alphonsus* in full illumination, and it has in this place a character different from the drawing of SCHMIDT.

2. This crater in SCHMIDT'S map is pear-shaped, with its longest dimension pointing toward A. Upon IV it appears to be of an elliptical shape, with the shorter axis in the direction of the libration, and it should therefore be really circular in form. Its position-angle and distance agree only partially with SCHMIDT'S values, although there can be no doubt as to the identification of the object.

3. On III there is in this place a dark intersection (which is bright in IV) of the northeast inner wall of *Arzachel*, which appears to constitute a saddle. The distances correspond to the points of beginning and ending, the position-angle to the middle point. The latter shows a large difference on III and IV, which is, however, entirely explained by the difference in the effects of libration. No such intersection is shown by SCHMIDT.

4. This object appears on III and IV to be entirely similar to No. 3, and is not given by SCHMIDT. Both 3 and 4 are clearly identified on both negatives, and form a characteristic of the northwest inner wall of *Arzachel*.

5. This crater on the northeast crest is designated by SCHMIDT and MAEDLER as *b*; it is not difficult to complete the contour in III, and on IV it is also easily seen if one imagines IV as a negative of III, or conversely. The distance given by SCHMIDT is too great, while the distances on III and IV agree well after the distance on III has been slightly diminished on account of libration, and that on IV has been increased for the same reason. The large difference of the position-angles on III and IV is again due to the effect of libration. Another Mount Hamilton negative (1891, July 14th—Moon's age $9^d\ 0^h$) shows the southeast wall of the crater very clearly.

6. SCHMIDT represents in this position a small crater on the eastern outer wall of *Arzachel*. The bright mountain-summit (concave toward *b*) in the same position on III is the representative of the southeast crater-wall; as is also plainly shown on the negative of 1891, July 14th, just mentioned. On IV this crater cannot be distinguished as such. According to NEISON the craters in the wall of *Arzachel* are particularly difficult to make out. Between objects 5 and 6, III shows a bright mountain crest which has the form of a figure 2, and which is also to be seen on IV. SCHMIDT has not succeeded in giving the character of the mountain-forms in this place, and still less MAEDLER, who represents the region as a level surface.

7. On III the high mountain valley *e* (NEISON) is shown admirably. This is the object which SCHMIDT has inserted in his *Catalogue of Rills* (1866) as a rill-valley (No. 308), but which was discovered by LOHRMANN in 1824. According

to III it is intersected in $p=136°$ by a conspicuous broad yoke, which SCHMIDT does not give. The northerly valley has in $p=123°$, on the inner side, a clearly marked curvature, which is laid down by SCHMIDT. This valley is particularly plain on IV. The distance d refers to the average distance of the double-valley, the position-angles to its beginning and ending. Here, also, SCHMIDT'S distance is larger. A third valley, likewise separate, is connected on the southwest to this double-valley. This third valley extends to $p=165°$, and is almost of the same length as the most northerly valley. From its north wall, according to III, a long mountain spur projects toward the southwest, which is not correctly given by SCHMIDT. On its southeasterly declivity is MAEDLER'S wall-crater Δ, which on III is in $p=174°$, $d=25.8$ *mm.* It is somewhat difficult to make out, but is much better seen on the Mount Hamilton negative of July 14, 1891.

8. East of the central mountain within *Arzachel*, IV shows a small dark spot, which appears as if it were a crater. SCHMIDT draws a very small crater, which agrees closely in position with this dark spot.

9. This crater north of *Thebit* appears (IV) toward the west as a continuation of a plainly marked mountain plateau, with a steep declivity, which is not represented in this way by SCHMIDT. It may be here remarked that the heliogravure is least successful in this neighborhood in its representation of the northern outliers of *Thebit*, between the crater last named and $p=180°$. The plate gives them as too hard.

10. On III there is a figure-of-eight shaped valley in this place, which SCHMIDT does not give. At least he does not give the evident cross-yoke formation in $p=209°$ which connects the southwestern interior crests with the outer crests. Beyond these a valley of considerable length stretches toward the north. NEISON refers to this and designates it by the letter *f*.

11. This position refers to the middle of the east wall of the ring-plain *e* (SCHMIDT) to the north of *Purbach*. SCHMIDT'S position-angle does not agree well with IV. It is to be remarked that the effect of libration alters nothing in this position, since this object lies near to the meridian of A and is far from the origin of coördinates O. This ring-plain also shows, in the interior toward the west, a depression of its floor parallel to the east wall, which is not referred to by SCHMIDT.

12. In this position, on the southwestern inner crest, IV shows a small, very black spot, which does not seem to be a defect in the plate, and which indicates either a steep lateral break in the wall or a small crater. The three small craters of SCHMIDT, which lie somewhat farther north on the same line of crests, should be visible on IV at the small outward curve of the shadow in this place.

13. This position refers to the strong curvature of the outer crests, where these take on a more northerly direction. III and IV agree well in p and d. The identi-

fication on SCHMIDT'S map is somewhat uncertain, since his drawing does not clearly express the general trend of the outer line of crests. The position is rightly chosen, however. The position-angle (according to SCHMIDT) is again considerably different.

14. This object on the western inner wall (IV) gives the impression of a crater, and is assumed to be identical with the wall-valley which SCHMIDT gives in this position.

15. This round crater on the northeast outer wall of the ring-plain *c* (SCHMIDT, MAEDLER) west of *Arzachel*, is very well shown on III; it is not within the limits of IV. The identification of this crater is beyond doubt, and it is therefore somewhat remarkable how greatly the position-angle of SCHMIDT differs from that on III, and that it differs in the same direction and by the same amount as for object No. 11. SCHMIDT'S position-angle is in error in this place, and this remark applies, naturally, to the entire neighboring region. To the north a large ring-plain is joined to this crater, which is well shown in III. It has a depression in its eastern interior portion, while the floor is drawn by SCHMIDT as entirely plane.

16. In this position III shows on the outer crest a crater-like formation, which is to be interpreted as a high mountain valley.

17. IV shows in this place a very plain and large crater formation, which can be seen on III also without difficulty. The difference in position-angle in SCHMIDT is of the same amount as in the case of object No. 15.

18. Here the northwest outer crests make on III and IV a sharp angle, whose position agrees closely on the two photographs. SCHMIDT does not characterize this angle so plainly as does MAEDLER. North of this there appears to be a descending valley, which is particularly well shown on IV.

19. Here IV clearly shows the beginning of the crater valley *e* (NEISON), which extends to the west from the high mountain peak *Alphonsus*, E. South of this lies a conspicuous cliff in a horseshoe form, which can also be seen on III.

20. This position designates, on III, the northeastern end of the serpentine rill inside of *Arzachel* which was discovered by SCHMIDT May 16, 1853, with the FRAUNHOFER telescope of the Berlin Observatory, and which is given as No. 309 in his *Catalogue of Rills*. Its sinuous form is plainly shown on III, but its character as a rill is not so evident. The position-angles differ considerably on account of the proximity of the object to the origin of coördinates. The place of the origin as given by SCHMIDT does not seem to be quite correct.

21. This crater on IV has a somewhat sharp-angled termination toward the northwest, and its form is a little exaggerated in the heliographic reproduction. To the west of this object the surface is by no means so smooth as it is drawn by SCHMIDT. On III the line of the rill, which originates at the northwest wall of

Arzachel, is plainly shown in the same position-angle, and tends with a gentle curvature toward this crater.

The *interior* of *Arzachel* is shown in especially rich and clear detail in figure IV. According to III the interior is not uniformly smooth in the northern and eastern parts, as it has the appearance of being in SCHMIDT'S map. Two diminutive craters in the line joining crater A to object No. 3 (one of which lies near A, the other quite on the border of the interior) are seen without difficulty on the original from which IV was made; but on the heliogravure they are barely indicated. On III, crater A has a small, bright appendage to its southeast wall, which corresponds to the small wall-crater which SCHMIDT figures in this situation. To the south of this (on III) the neighboring large crater can be made out by its eastern wall and faint shadow. This is shown on IV, but not so plainly, by its western bright wall. The crater-valley at the southern outliers of the central peak can also be better seen on III than on IV. From the northern end of this (on IV) a plainly marked, bright, division-line extends westward to the foot of the mountain, dividing it into two parts. This should appear on III as a dark line, but it is nevertheless entirely lacking. The reason of this is that the exposure-time of the plate of August 15, 1888, was not entirely suitable for *Arzachel.* In this respect the plate taken July 14, 1891, is much more detailed. On the latter the dark line in question is given very clearly, the crater between this and A is strongly marked, and on the bright eastern wall of *Arzachel* many dark terrace-lines are shown, and indeed there is manifold detail even within the deep shadow. In passing, it may be remarked that this negative shows the crater *d* north of *Archimedes* plainly, as well as its shadow. If I had been in possession of this negative of July 14, 1891, at the time I commenced my drawing of *Arzachel* I should have used it in preference to that of August 15, 1888, and should have been able to present representation III fully equal to IV. As the shadows are entirely alike on the two negatives last mentioned, and as *Arzachel* is equally distant from the terminator on both,* the comparison just made affords a good illustration of the great importance of giving the exact exposure-time required for a special object, if it is wished to faithfully reproduce the smallest details; and it illustrates also the necessity for having access to several negatives of the same age of the Moon, if any neighborhood is to be studied minutely.†

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* The effect of the libration is, however, different in the two plates. For example, the negative of 1891 shows crater A, as well as the objects Nos. 5, 15, 21, round, and not extended.

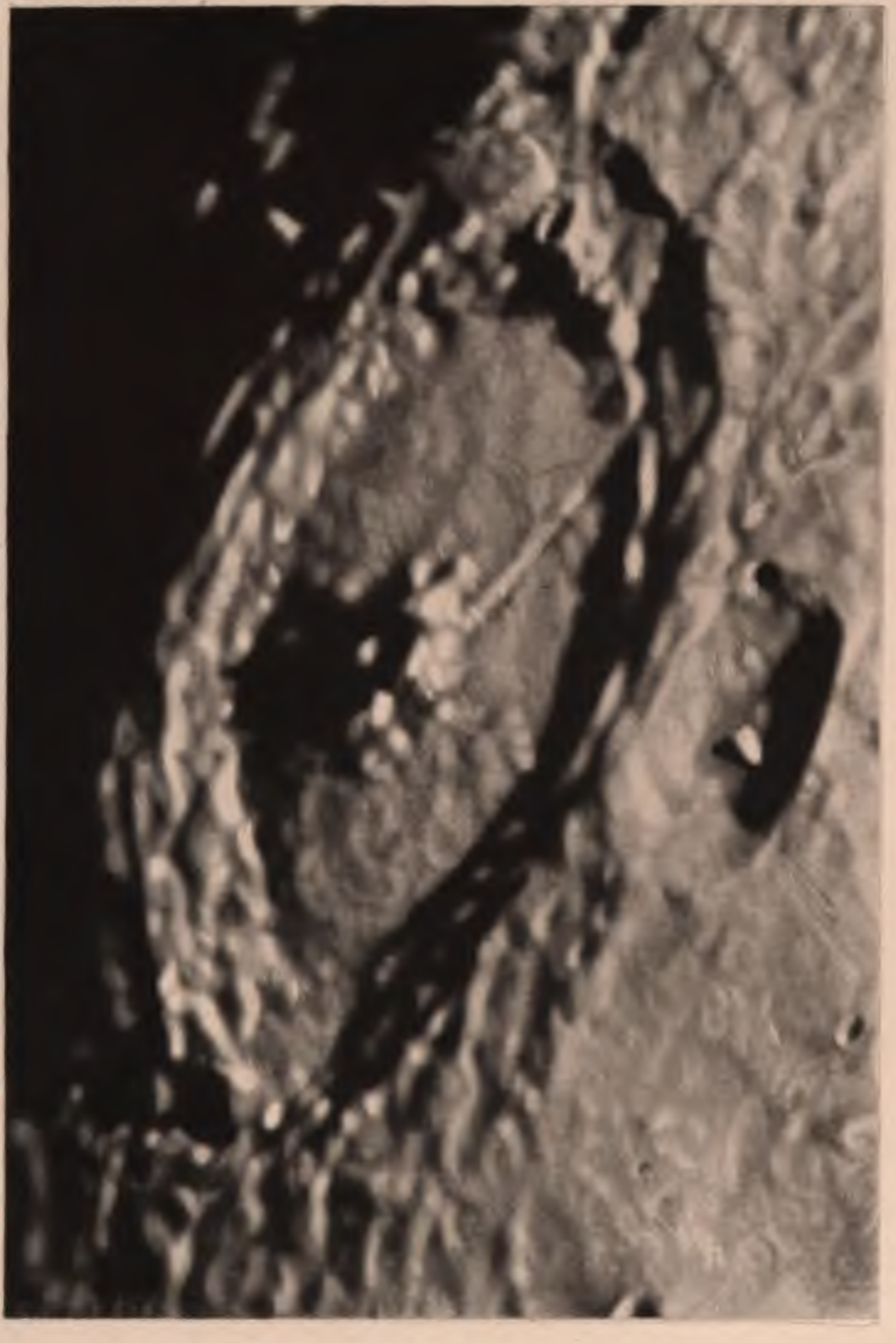
† The exposures for the Moon, with the full aperture of the great telescope, are never more than a few tenths of a second, and even when the aperture is reduced to 12 or 8 inches, they seldom exceed three seconds. Different objects on the Moon appear in all possible brilliancies, from the maximum brightness of *Aristarchus* to the deepest shadows, and it is not practicable to vary the exposure-time of the original negatives, so as to insure that *all* the features of the surface shall be shown, each with its appropriate exposure-time. The exposure-times of the original negatives now

In concluding this comparison, it may be stated generally that SCHMIDT has not entirely succeeded in displaying the character of the mountain landscape in the neighborhood of *Arzachel* in all its particularities, and this is readily comprehensible when we consider its great complexity, and the difficulty of delineating it on a map. The representation given by SCHMIDT is, in spite of all drawbacks, most admirable. With reference to the heliographic reproduction of my original drawings of *Arzachel*, the remarks which I have already made on those of *Archimedes* are entirely applicable. Finally, I may refer to an interesting optical delusion, to which Professor HOLDEN has called my attention, with reference to figures III and IV. If the plate is correctly held with the numerals III and IV *above*, the interior of the ring-plain appears convex on III and concave on IV. If the numerals III and IV are *below*, the effect is reversed. If the plate be rotated in a plane perpendicular to the line of sight, the convexities and concavities go through a cycle of changes which are usually the same for each observer, but which differ with different observers. The explanation of this is obvious, and the phenomenon is well known.

L. WEINEK.

Prague, 1891, December 4.

taken at the Lick Observatory are, however, varied considerably in accordance with the suggestion of Professor WEINEK. I have pointed out a method (*Publications of the Astronomical Society of the Pacific*, vol. III (1891), page 249) by which at least some of the advantages which I have spoken of may be secured in the subsequent copyings of the plate, and it is not yet certain that this method, properly used, may not give all that is desirable.—E. S. H.



PETAVIUS

DRAWING BY PROFESSOR L. WEINEK, ENLARGED TWENTY-FOLD

FROM THE NEGATIVE TAKEN AT THE LICK OBSERVATORY ON AUGUST 31, 1890.

DRAWING OF PETAVIUS.*

(See the heliogravure plate facing this page, the lithograph, and the wood-cut in the text.)

During the progress of my 10-fold enlarged drawing of *Arzachel* from the fine Mount Hamilton negative of August 27, 1888, which is so rich in details, it occurred to me that it would be desirable to extend the scale of enlargement still further, because, in the first place, an enlarged scale would allow a freer use of the brush, and secondly, because the detail of a larger drawing would be better reproduced by the process chosen for illustration. I decided to take the step to a 20-fold enlargement at once, although I did not then appreciate the difficulties thus introduced in copying such a mosaic-like object, by the considerable limitation of the field of view of the higher-power eye-piece employed.

I accordingly obtained from the optical establishment of Messrs. REINFELDER & HERTEL, in Munich, a very fine achromatic micrometer eye-piece of half a Paris inch (13.53 *mm.*) equivalent focus. As my distance of distinct vision is 28 *cm.*, it follows that the linear magnifying power of this eye-piece is, for me, 21.7 diameters. This eye-piece, if used in connection with the Mount Hamilton telescope, whose photographic focus is 14.483 *meters*, would correspond to a magnifying power of 1070 diameters. According to what has been said in speaking of the enlargements of *Archimedes*, it follows that a 20-fold enlargement of the Mount Hamilton negatives corresponds to a drawing of the Moon of about 2.8 (110 inches, or over 9 feet) in diameter.

The use of a glass reticle divided into square *millimeters* in the manner which has been previously described required that the smallest squares of the enlarged drawing should have sides as large as 2 *centimeters.* After sufficient practice it was found that such squares were not too large to allow the details to be inserted by estimation of their relative positions. Trusting that my great inclination for the work would overcome the difficulties of the actual drawing, which include the most painstaking study of the original as well as the greatest completeness in the representation of it, I began on June 23, 1891, the 20-fold enlargement of *Petavius* from the admirable Mount Hamilton negative of August

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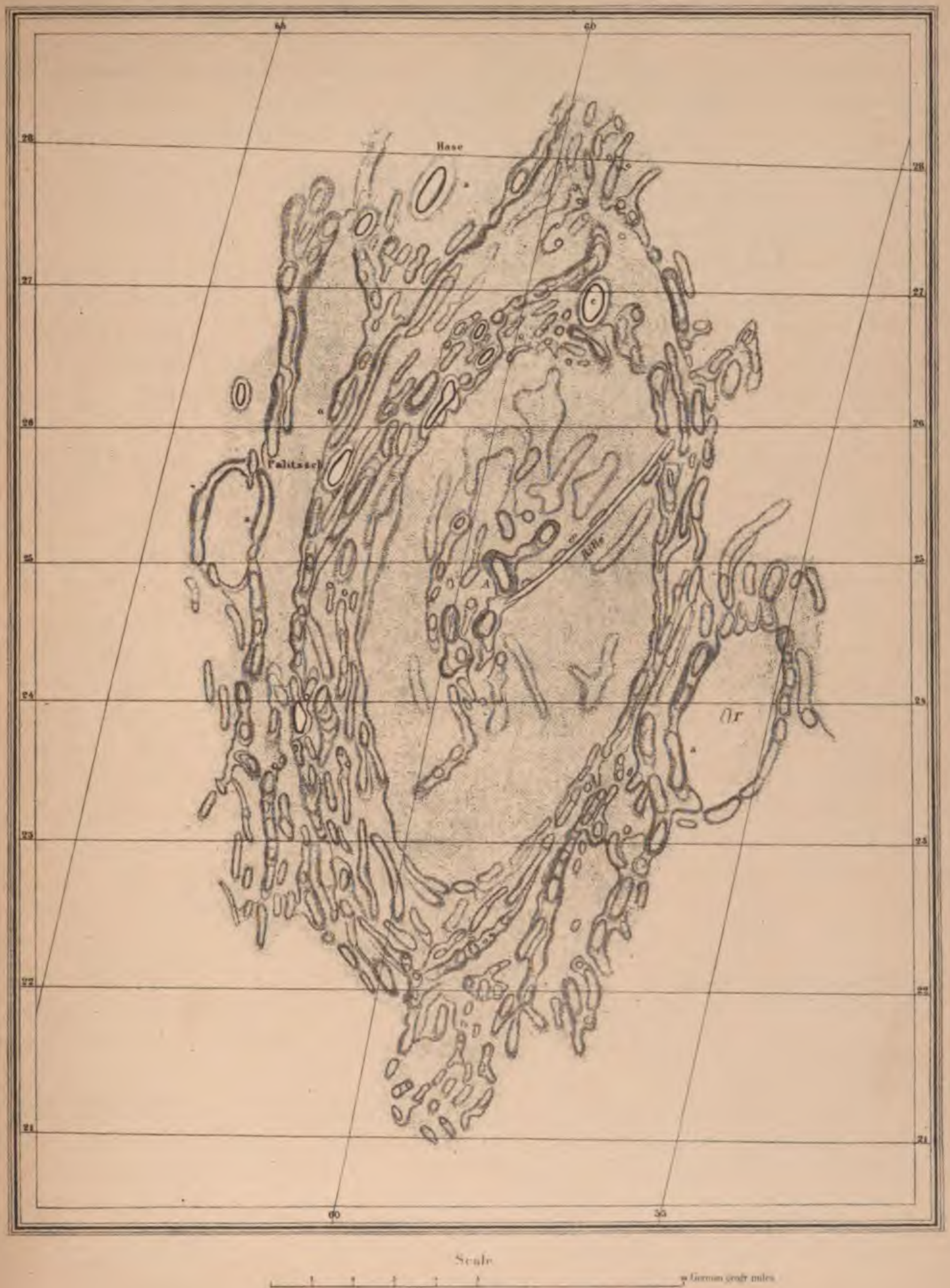
* Translated by EDWARD S. HOLDEN.

31, 1890, taken at $14^h\ 27^m$, P. S. T. (Pacific standard time + 8 hours = Greenwich mean time). A second plate, taken two minutes earlier on the same night, served as a control and to eliminate occasional defects in the film of the first-named negative. I chose this object (*Petavius*) particularly because MAEDLER had constructed a special chart of it on almost the same scale, and as it appeared profitable to supplement his schematic drawing by a plastic representation as complete as possible, and also because an estimate of the agreement between the two drawings would not be without interest. The drawing (12x18 *centimeters* in size) was completed November 23, 1891 (I was absent from Prague during two of the summer months), and it required in all 120½ actual working hours. The original drawing may be considered as completely successful; the heliogravure is considerably less satisfactory than the drawing in respect of the lighting, the fineness of the transition tones, and in the richness as well as the clearness of its details. It may serve to characterize the degree in which the heliogravure falls behind the original drawing if I say that I should consider it necessary to put from 30 to 40 hours more work upon a drawing of equal excellence with the heliogravure, before I should regard such a drawing as completed. In spite of this criticism the plate must be considered as a successful reproduction. Its lacks are due to the great technical difficulties in printing such copies and to the nature of the heliogravure process itself.

According to the table on page 65, the work on this drawing extended over 52 days, with a daily average of 2.32 hours. During the actual process of making the picture there was a special pleasure in the effort to give a true representation of the crater as a whole, in spite of the difficulties introduced by the fact that the eye-piece employed only showed a small fraction of the formation at one view. It was naturally necessary, after the completion of this step-by-step process, to review the work by means of an eye-piece having less magnifying power, in order to obtain by this second study and comparison a true representation of the relative lights and shades of the original picture. This review was made by means of an eye-piece of 41.15 *mm.* equivalent focal length, with a linear magnification of 7.8; and the depths of shadow in the drawing were adopted as they appeared in this eye-piece. Again, only the more important particularities which the drawing revealed, in addition to the representations of MAEDLER and of SCHMIDT, were depicted. For it is not possible to include every detail without making separate drawings and without introducing new designations of the different single objects. To go into the finer detail of a 20-fold enlargement would involve the construction of an entirely new chart of *Petavius;* so manifold are the new forms which light has depicted on the sensitive film of the plate. The comparisons are principally made with MAEDLER'S large special chart made by him in Dorpat, in 1832, "on four



PETAVIUS ACCORDING TO J H MAEDLER

admirably clear nights" (January 9, 10, March 4, 6),* and also with SCHMIDT'S map, Section X. For shortness, I shall denote the former by M, the latter by S, and my 20-fold enlargement by W.

Summary of the Working Hours Employed upon the Drawing of Petavius (1:20) from the Mount Hamilton Negative of August 31, 1890.

1891.	A. M.	P. M.	No. of Hours.	1891.	A. M.	P. M.	No. of Hours.
	h	*h*			*h*	*h*	
June 23	. . . . . .	2½–4	1.5	October 27 . . .	. . . . . .	2–2½	0.5
June 24	9–11½	2¼–4¾	5	October 28 . . .	9–12	2½–3½	4
June 25	7–8	2¼–3¾	2.5	October 29 . . .	9–10½	. . . . . .	1.5
June 26	9–10½	2½–5	4	October 30 . . .	9–10¼	2–3¼	2.5
June 27	8–9½	2½–4	3	October 31 . . .	. . . . . .	2–3½	1.5
September 28 . .	9¾–12	. . . . . .	2.25	November 1 . .	10½–11½	2–2½	1.5
October 4	. . . . . .	2¾–3¾	1	November 2 . .	8–12	. . . . . .	4
October 6	. . . . . .	2–3½	1.5	November 3 . .	8½–9½	2–3	2
October 7	9–11	2½–3½	3	November 4 . .	9–11	2½–3½	3
October 8	10–11¾	. . . . . .	1.75	November 5 . .	9–9½	2–3½	2
October 9	9½–11	2–3½	3	November 6 . .	9–11½	2–3	3.5
October 10	. . . . . .	1½–3½	2	November 7 . .	. . . . . .	2–3½	1.5
October 11	11½–12	2½–3½	1.5	November 8 . .	10–11½	2¼–3¼	2.5
October 13	. . . . . .	2–3½	1.5	November 9 . .	10–12	2½–3	2.5
October 15	. . . . . .	2–3½	1.5	November 10 . .	10–11¼	2–2¼	1.5
October 16	10–12	2–3½	3.5	November 11 . .	10–12	2–2½	2.5
October 17	9–10¾	2–3¼	3	November 12 . .	. . . . . .	2–2½	0.5
October 18	10–12	2–3	3	November 13 . .	9–11½	2–3	3.5
October 19	9–12	2–3	4	November 14 . .	11–12	2–2½	1.5
October 20	. . . . . .	2–3½	1.5	November 15 . .	9–12¼	2–3	4.25
October 21	10–11½	2¼–3¾	3	November 16 . .	10½–11½	. . . . . .	1
October 22	9–10	2–3½	2.5	November 17 . .	. . . . . .	2–2½	0.5
October 23	9½–11½	2–3	3	November 18 . .	10–11	2¼–2¾	1.5
October 24	. . . . . .	2–3	1	November 19 . .	. . . . . .	1½–2½	1
October 25	9½–12	2–3½	4	November 20 . .	10–12¼	. . . . . .	2.25
October 26	11–12	2½–3½	2	November 23 . .	10–12½	. . . . . .	2.5
Sum—hours						120.5	
Number of days						52	
Average number of hours per day						2.32	

The wall of *Petavius* is in its general features best shown in MAEDLER'S *Mappa Selenographica*, and its separate features in his special chart (which I shall call M). In this latter respect, SCHMIDT'S map (S) is the least successful, for it is often difficult to identify the characteristic features. The method of drawing adopted by SCHMIDT gives, generally, only the bright separate line of crests, and often leaves the declivities perpendicular to these entirely out of account. The convex interior surface, with its well-known great *rill*, is only shown by MAEDLER and by SCHMIDT in its principal features—better by the latter selenographer. The 20-fold enlargement gives, in this respect, the completest details and the finest changes of level of the *terrain*, which up to this time have not been fixed by any chart. On the other hand, the enlargement shows in the southern interior several faint rills,* which constitute, if they are indeed veritable rills, noteworthy evidence of the excellence of the photographic process. The central mountain is better shown on M than on S, although M still leaves something to be desired in this respect. Let us now make comparisons of the single features. The selenographical positions which I shall give, λ (+ if west) and β (+ if north), are taken from the chart M.

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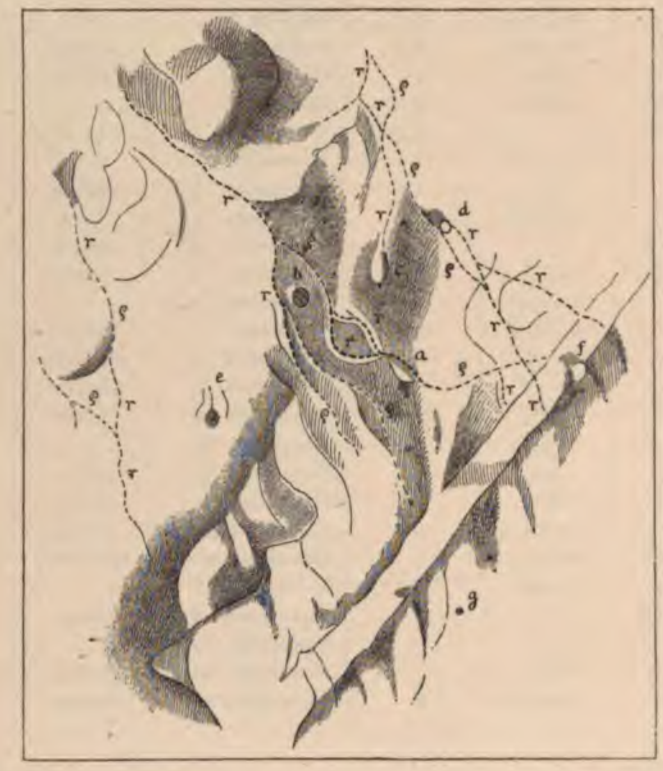
* See the accompanying lithographic plate, which reproduces MAEDLER'S chart reduced to the scale of my drawing.



1. In the first place it appears that Schmidt has drawn the ring-plain *Petavius a* (*Wrottesley*, according to Neison) too far to the north. According to Maedler, its place is more correctly given in M than in the *Mappa Selenographica*.

2. A long declivity is connected with *Wrottesley* toward the north, in the direction of the west wall of this ring-plain. The contours of this are tolerably correct in M, and inexact in S. On the high plateau of this declivity Maedler and Schmidt depict large plane areas, which do not exist according to W. In $\lambda = +57^\circ.3$, $\beta = -22^\circ.5$ (center), M fails to show a long terrace-like slope, while the pass lying to the west is plainly exhibited. In $\lambda = +56^\circ.3$, $\beta = -23^\circ.0$, W depicts a chain of three craters (the southernmost of which, however, is only doubtfully shown as a crater), which lie on the eastern crest of the declivity in

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* I use this expression in a general sense, and I mean by it to denote shallow depressions on the Moon, which are usually of considerable length and of relatively small width.

question. Moreover, the object in $\lambda = +56^\circ.9$, $\beta = -23^\circ.1$ also has the appearance of a crater; so that in this neighborhood there are three or four craters which do not appear either in M or in S.

3. In $\lambda = +55^\circ.3$, $\beta = -22^\circ.7$ (center) a second declivity runs in the direction of the east wall of *Wrottesley* and north from it. With a low magnifying power this, in the Mount Hamilton negative employed, and also in that of August 23, 1888, gives the impression of a rill-like valley. SCHMIDT shows in this place a complex system of small craters. In M nothing is given.

4. The valley, just described, extends to the north to a small crater, which has a diameter of only 0.15 *mm.* on the photographic plate (and yet is plainly visible), and which is easily identified on S. Southeast of it lies a larger crater (on the right hand lower edge of the drawing W), which is drawn by SCHMIDT too close to the first-named crater. This is caused by the erroneous position of *Wrottesley* upon S. According to W, a fine rift or *rill* seems to issue from the first-named crater toward the northeast.

5. On the lower edge of the drawing W the southern end of the crater *Petavius* B is to be seen. MAEDLER (*Mappa Selenographica*) and NEISON have there a small wall-crater, which does not appear on W, and is also not indicated by S.

6. The western, southern, and northern walls of *Wrottesley* have, according to W, a broad, gradual slope, which is indicated by SCHMIDT, but which MAEDLER shows as entirely precipitous. This slope gives to the interior a tunnel-shaped appearance. The central peak γ (MAEDLER) is single in M, 3-fold in S. W shows two peaks, the southernmost of which must be comparatively low, however. The cross-cleft which SCHMIDT shows on the most northerly may have been lost in the negative on account of the exposure-time. On the northeast crest of this ring-plain there appears to be a short pass, according to W, from which a narrow rill issues toward the northeast. There is nothing like this in S.

7. In $\lambda = +55^\circ.8$, $\beta = -24^\circ.7$, at the southern crest of the wall of *Wrottesley*, W shows a large crater. M does not give this; S, on the other hand, shows three small craters in this place. South of this, W shows another shallow crater-like formation, which is not given by S or M.

8. The crater *c* on the southern inner wall of *Petavius* lies, according to W, at the crest of the wall and does not break through it, as it appears to do in S. M agrees with W as to this. At the southwest wall of this crater, W shows a bright streak, which extends toward the west and which appears not unlike an elevated ridge. M and S do not depict this feature.

9. In $\lambda = +60^\circ.3$, $\beta = -26^\circ.7$, W shows on the southwest inner wall of *Petavius* a wavy cross-wall, shown also by M, which is not given by S. M draws north of this, and immediately adjacent, two larger craters, which are tolerably plainly

shown in W, in spite of the shadow of the above-named cross-wall which falls upon them. These craters are also well shown in my small drawing of *Petavius* (in the *Prague Astronomical Observations* of 1885, 1886, 1887), but they are free from the shadow of the cross-wall, which is only to be seen in that situation when the Sun is very far south. North of this M has (in $\lambda = +60°.9, \beta = -26°.2$) a long crater-valley in a nearly meridional direction, which is not to be seen, as such, on W, nor on S. The rest of the west and northwest wall of *Petavius* is represented by M correctly as to its chief features, and particularly as to its inner boundary. This is not so in S, upon which single formations are placed too far to the south.

10. South of the central peak A, W shows a bifurcation of the mountains, which has the appearance of a crater, but neither M nor S show it in this way.

11. In the southern interior the chief objects shown on W are two plainly marked walls in the direction of the meridian; the easternmost of these extends toward the north over the great rill and is correctly given by S in its main features. In $\lambda = +60°.7, \beta = -25°.9$, W shows two large semi-circular depressions on the inner southwest border which are missing in M and in S. In particular, the hummock-like nature of the southern parts of the interior is only imperfectly given by MAEDLER and SCHMIDT, and in the northern parts this hummock-like interior is scarcely indicated at all.

12. In $\lambda = +60°.2, \beta = -25°.3$, M shows a small crater westward from the southern outliers of the central peak which is not given on W. On the *Mappa Selenographica* two craters are laid down in this place; but NEISON remarks that these are doubtful, and that the surface sometimes appears to have two small depressions here.

13. On the other hand, W shows in $\lambda = +59°.6, \beta = -26°.0$ a small crater formation, and again in $\lambda = +58°.7, \beta = -25°.7$ an elongated crater-fork, through which goes a narrow rill, whose bright walls are occasionally seen. This originates at the southwest wall, north from the crater spoken of above (No. 9), and can be followed in a wavy line directly through the southern interior to the great rill, and up to its southwestern precipices. North of the center of the great rill, S draws a very small crater, which is plainly seen on W. In the southern interior there are other narrow rills, one of which debouches into a kind of a crater-pit, which is also shown in the northern interior.

14. The great *Petavius-Rill* has a greater breadth than MAEDLER gives to it. According to W, there is in $\lambda = +58°.2, \beta = -25°.3$ (that is, near its middle point), a *knee*, which is not recorded by any selenographer. Furthermore, a bright cross-streak is shown near the central mountain, which is not unlike a rock-bridge. Both borders of the great rill appear hilly, and this is especially

obvious on the eastern side. (It should be noted that this character was pointed out years ago by Mr. ELGER, though it was denied by other selenographers.) The curvilinear direction of this rill, with the convex side toward the northeast, is correctly represented on M. On S it is rectilinear.

If the entire delicate and wonderful detail drawn in the interior of *Petavius*[*] should be confirmed by visual observations or by repeated photographic pictures, it will be an evidence of the great value of the photographic results of the Lick Observatory to selenography. Then also I trust that the present plastic representation of *Petavius* (the first to be given on so large a scale) will be found to have its worth for all time as a true representation of nature. I may remark, in conclusion, that my small *Petavius* drawing above referred to, which was made with the 6-inch telescope of the Prague Observatory, June 18, 1886, agrees well, in all important points, with the photograph, although it corresponds to a somewhat greater altitude of the Sun.

L. WEINEK.

Prague, 1891, December 19.

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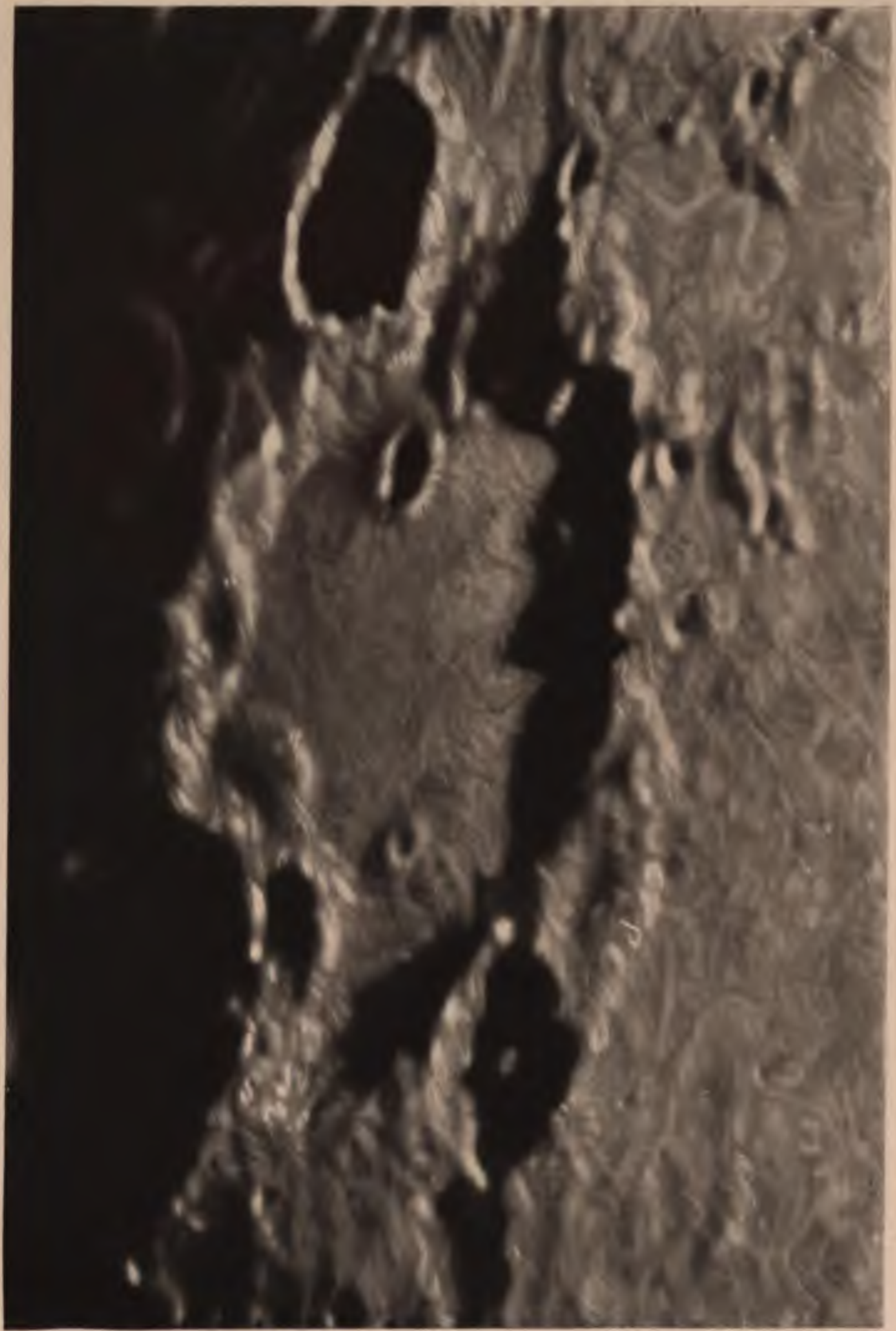
[*] It should be remarked that the narrow rills in the southern interior, on W, have a width of about 0.1 *mm.*, and that the originals on the negative are therefore about 0.005 *mm.*



VENDELINUS.

DRAWING BY PROFESSOR L. WEINEK, ENLARGED TWENTY-FOLD
FROM THE NEGATIVE TAKEN AT THE LICK OBSERVATORY ON AUGUST 31, 1890.

DRAWING OF VENDELINUS.*

(See the heliogravure plate facing this page.)

This drawing, like those of *Petavius* and *Langrenus*, was enlarged 20-fold from an admirable *dia-positive* corresponding to the Mount Hamilton negative of 1890, August 31, $14^h\ 27^m$, P. S. T., employing for the enlargement a glass reticle ruled in squares of a *millimeter* on the side. As the fields including *Vendelinus* and *Langrenus* are adjacent to each other on the Moon, the two drawings were so made as to accurately join each other and to make, thus juxtaposed, a single representation of the two craters 12 *cm.* wide and 36 *cm.* high. In order to effect this junction of the two drawings, the glass reticle was not removed from the *dia-positive* until the contours for both the craters were laid down. It is to be regretted that it was not practicable to print the heliogravures representing the two drawings as one plate.

The time spent on the drawing of *Vendelinus* alone was 122.0 hours. The drawing is full of manifold and delicate detail, and the heliogravure (made by the k. u. k. Militär-geographisches Institut in Wien) reproduces this detail very successfully. I may mention, also, that I have drawn this same crater on a smaller scale with the 6-inch refractor of the Prague Observatory on September 30, 1890 (in 1¾ hours, see *Prager Astronomische Beobachtungen*, 1888–1891), and that this drawing agrees excellently throughout with the photograph in its character, and in its contour in general. The same cannot be said of several recent drawings of the same object, which have lately been published in Germany and England.

The comparison of my 20-fold drawing has been made especially with SCHMIDT'S Atlas, Section X, and with a second Mount Hamilton photograph, taken on the same night, two minutes earlier, at $14^h\ 25^m$. The latter plate is inferior to the plate at $14^h\ 27^m$, especially in respect to the fineness of the grain of the film. Comparisons have also been made with the drawing of *Vendelinus* by ELGER on December 17, 1891 (see *English Mechanic*, January 15, 1892, and *Memoirs of the British Astronomical Association*, vol. II, part II); with the contour-sketch of the northern interior parts of this crater by MAW, based on all his observations of 1892

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* Translated by EDWARD S. HOLDEN. It was necessary to send this translation to the printer before it had received a final revision by Professor WEINEK.

(*op. cit.* vol. II, part II), and on the latest drawing of KRIEGER, made on August 18, 1893. The nomenclature of the separate objects has been chosen from SCHMIDT.

1. According to the photograph, there is in the west wall a well-marked angle (corner), in the east wall an obvious notch (cut). If these two objects are joined together, and if we also join the centers of the ring-plains A (to the north) and B (to the south) by a second line, it will be found that the angle of the lines toward the southwest is obtuse, whereas SCHMIDT represents it as acute. He has also placed the western corner too far to the south, and the eastern notch too far to the north. SCHMIDT'S drawing of the southwest wall makes it too narrow and characterless, and the most northerly parts of the interior, where they merge into the outer plateau, are also too narrow. This depends upon the fact that SCHMIDT has located the ring-plain A, as a whole, too far to the west. Its west wall should be the curved continuation of the east wall of the main crater. On the other hand, the form as given by SCHMIDT is very nearly correct, which is not the case for ELGER and KRIEGER. On the northwest wall of *Vendelinus* lie two large oval, basin-like, formations, which have been called "landslips" by several selenographers. This designation does not appear to be a felicitous one, and it can under no circumstances be applied to the northern formation, which has a decided crateriform character. The photograph shows that both of them appertain to the base of the wall, and that they are connected together, while SCHMIDT so represents them that one might regard them as separate. The well-known characteristic shadow of the east wall, which portrays the form of a human profile turned to the east, the eye being formed by the crater E, is very well shown in the photograph. The line joining the notch in the east wall with the under-lip of the profile corresponds to the direction in which the Sun's rays lie.

2. According to the photograph the interior of the crater is slightly convex, and nowhere a completely plane surface. Several low elevations project above it. The most marked of these lie on the western border, in a north and south direction; and, again, east of crater E, first in a northwesterly and then in a northerly direction. These are not given by SCHMIDT and ELGER. The well-marked crater in the northern interior is called *h* by SCHMIDT. It appears to have, in the south, a westerly sinking of its wall, which has not been previously remarked.

The southern larger crater, E, is drawn by ELGER with a short elevation attached to its north wall. According to the photograph there should be here an opening in the wall, and a rill-like high valley which stretches toward the north. The crater west of E is not to be seen in the photograph, because it is covered by the shadow of E, but the neighboring crater to the northwest is visible.

3. Serious criticisms of this drawing of *Vendelinus*, based on the fact that it does not show certain obvious craters in the interior at all, have been made, and

the entirely erroneous conclusion has been drawn, based on this lack, that the finer detail which is shown cannot be considered as real. Let us consider this matter a little more closely. In the chapter on *Langrenus*, I have given a convincing example of the fact that a photographic plate, otherwise satisfactory, may have received such an exposure-time as to fail to show the crater-character even of large and conspicuous objects. In such cases the background of the object, its brightness, its color, etc., play an important rôle. In most cases, however, even when the exposure is very far from being the suitable one for the purpose of showing such craters, the crater is still depicted on the negative, frequently as a mere faint outline, which is easily overlooked in a careless inspection, or if the observer has little practice in such examinations. These remarks apply exactly to the cases of small craters in the interior of *Vendelinus* on the negative employed. The exposure of this negative is very suitable for depicting many, indeed most, features; but it happens to be unsuitable for the small craters in question, and for some other objects of like kind similarly illuminated. Yet a careful examination of the photograph will bring to light almost every one of the small craters in the interior of *Vendelinus;* and from such an examination it will at once be shown how materially the visual observers of these objects—SCHMIDT, ELGER, KRIEGER, and MAW—differ in the positions which they have assigned to them.

Northeasterly from E, about half the distance from E to the east wall, ELGER has drawn two small craters near together, the line joining them being parallel to the north wall of B. SCHMIDT lays them down still nearer to the east wall. The photograph plainly shows these two craters to be at the ends of the two rills east of the north wall of E. The places of these knots in the rills agree well with ELGER'S observation. The photograph also shows, to the south, a crater-like depression, whose character as such is confirmed by the fine rills which there debouch. According to MAW, the crater *h* has connected to it, toward the east, a forked elevation, with one branch toward the northeast, the other toward the southeast. The first branch has two craters (*l* and *u*), the second, three (*x*, *w*, *y*). The photograph shows *l* and *u*, and especially *l*, very plainly, and fully confirms MAW'S observation of the low-forked elevation. *x* and *y* are also to be found on the photograph. The former is particularly plain on the plate taken at $14^h\ 25^m$. SCHMIDT lays down the craters *l*, *u*, *x* plainly, but gives no elevated area in this place. The same may be said of ELGER and KRIEGER. KRIEGER does not give the craters *l* and *u*, but includes a crater farther to the north, which MAW calls *s*. According to both observers there is a rill which extends to the north from *s*. ELGER has only a single crater east of *h*, which, to judge from its position, may be *l*. If this identification is correct, it is too far to the south. West of *h* SCHMIDT and KRIEGER have two craters, ELGER but one, and MAW also but one (*q*), which latter is much more distant than ELGER'S. The photograph gives two craters, near to the northwest wall. The crater drawn by ELGER south of the east wall of *h* is to be found on the photograph also; and the photograph indicates also another small crater between the last named and *h*.

What precedes may suffice to show that visual observations like the foregoing require to be made with much greater care before they will serve as a basis for the conclusion that the results of photography are not to be trusted. The reverse process is more nearly the correct one. The subjective impressions of the observer at the telescope frequently require to be rectified by the objective testimony of the sensitive plate (where, naturally, several negatives of different exposure-times are needed).

4. In the interior of *Vendelinus* SCHMIDT has drawn no rills; but on the north border he has a crater-rill, near to and parallel with the northwest wall of the ring-plain A, which debouches in the ring-plain *e*. SCHMIDT'S description of this is as follows: "1851, February 17 (Bonn). West and northwest of *Vendelinus*, A, I drew a well-marked rill, which I later resolved, with the Athens refractor, into a series of craters." Its course and its crateriform character are easily made out on the photograph. ELGER shows this rill connected with the north border of the crater *h* by a shallow rill; whereas SCHMIDT draws in this place an elevation lying north and south. The photograph seems to show here a rill-valley, lying between low hills, which is, however, not so regular and straight as ELGER'S drawing. West of SCHMIDT'S crater-rill, ELGER has another well-marked rill. Its course, which is directed toward a larger crater, is very plain on the photograph; and the latter shows it to possess, also, a sharply-marked branch to the east, which runs parallel to the crater-rill of SCHMIDT, just referred to. Between the latter and the branch just described there lies an obvious crater, which ELGER has not seen. It is on both of the Lick plates.

5. In the northwestern and northern interior KRIEGER discovered two rills on June 26, 1891. One of these was independently discovered by MAW on October 7, 1892, and is described above in paragraph 3. The latter rill lies, in the photograph, within the shadow of the northeast wall, and is therefore not visible. The northern portion of the other is, however, shown in the photograph southwest of the crater *h*, where it passes toward the south from the southernmost one of the two small craters previously described. There appears, however, near this southernmost crater, to be a branch bending off in the direction of the crater *h*; and in the immediate vicinity, to the east, still another fine companion-rill, which is also directed toward *h*.

6. The photograph shows several other rill-formations in the interior, which are in part of great interest. The most important is a large oval formation with ruptured walls, which incloses the corner of the mouth of the shadow of the east wall, and which lies in the eastern central parts of the interior. Its principal out-

lines are also visible on the Mount Hamilton plate of 14^h 25^m. I may mention others, as follows: The rills east and northeast of the crater E, which run nearly at right angles with the direction of the Sun's rays; the rill at the interior western border, whose southern branch cuts through the elevation there situated; the northern branch of the same rill divides again and extends still further northeasterly (resembling a low elevation in appearance) till it reaches the oval rill-formation described above. Northwest of the northern branch lies a fine rill at the distance of the north and south diameter of *h*, which seems to lead to a small crater; and at about double this distance is still another rill, running at right angles with the direction of the Sun's rays, which traverses the west wall, the west corner of the interior, and the northwest wall of *Vendelinus*.

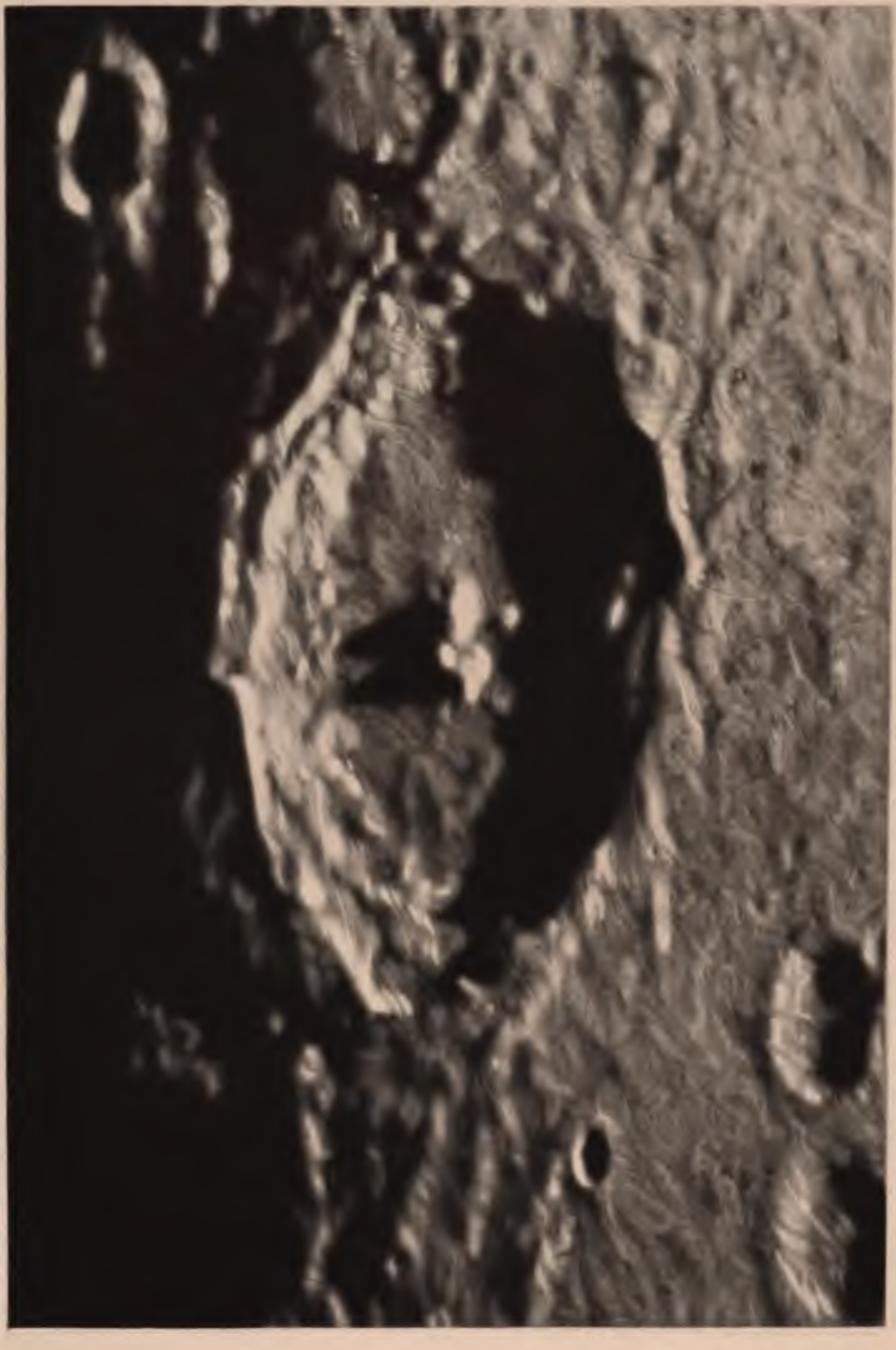
7. North of the crater E the valley formation above described continues to a small oval figure, with its longer axis in the meridian, which has an obviously convex interior surface, and which has triple limiting lines, nearly parallel among themselves, on the east side. A short rill is connected with this on the northeast. A noteworthy structure lies south of the crater *h*, at a distance of about two of the north and south diameters of that crater. It is a large, long, closed figure, with doubled and somewhat symmetric limiting lines, and its true nature is problematical.

8. The surroundings of *Vendelinus* are rich in detail, but I shall dismiss them in a few words. On the east wall, the heliogravure shows, at the same distance from the edge as the crater E, a large, very obvious crater, which is laid down by SCHMIDT, but not by ELGER. The photograph indicates another crater formation west of this, and connected with it, which is not so drawn by SCHMIDT. From this latter two fine rills run to the northeast, converging as they go. East of the cut in the east wall lies a crater which is at least as large as *h*, and is very plain on the photograph. To the northeast of this lies a smaller crater, which has been seen by SCHMIDT, but not by ELGER. The photograph shows it to be traversed by a very long and remarkable rill-valley lying northeast and north, with crater-like enlargements; in its northern course it acquires the character of an elevated ridge, and lies parallel to the ring-plain A. This rill-valley is cut by several other rills. Rills are to be found, in fact, in nearly every part of the eastern neighborhood of *Vendelinus*.

No further verbal description need be given here, but reference is made to the heliogravure. This plate and those of *Petavius* and *Langrenus*, together with the brief sections which I have written descriptive of the regions including these craters, will illustrate the excellence of the Mount Hamilton plate from which I have made the drawings.

L. WEINEK.

Prague, 1894.



LANGRENUS.

DRAWING BY PROFESSOR L. WEINEK. ENLARGED TWENTY-FOLD

FROM THE NEGATIVE TAKEN AT THE LICK OBSERVATORY ON AUGUST 31, 1890.

LANGRENUS.[*]

(See the heliogravure plate facing this page.)

My 20-fold enlarged drawing of *Langrenus* was made in 127½ hours from a beautiful contact positive (I) on glass from the negative taken with the 36-inch telescope on August 31, 1890, at $14^h\ 27^m$, P. S. T. I have also a second positive (II) corresponding to an exposure-time about 2^m earlier, which is, however (as remarked in the Prague *Astronomical Observations*, vol. 1888–1891, page 75), too dark in tone and too coarse in grain to be used with advantage in verifying the finer details of I.

I take this occasion to controvert the frequently expressed opinion that two photographic plates taken with the same exposure-time, and within a few minutes of each other, must *necessarily* exhibit the same fine details throughout. In general, they will not do so, (*a*) because the steadiness of the atmosphere varies from plate to plate; (*b*) because the sensitiveness of the films of commercial dry plates varies from plate to plate; (*c*) because in the development or the intensification of the photographic image (during exposure) there are moments of varying definition; and finally (*d*) because in copying the original negatives on different plates variations in the illumination, exposure-time, films, etc., are likely to occur.[†] A striking example of this is the following: My drawing of *Langrenus* shows in the middle of the upper margin of the picture a large crater, to the right (east) of which is a smaller one. This latter appears on I completely clear and sharp, whereas on II it is so indefinite that one would hardly take it for a crater-like object, unless its character were known beforehand. It is obvious, moreover, that even in the representation of very small craters the correct exposure-time plays a very important rôle. Where the exposure-time is not the right one the object will be flat; the shadows of the crater will lose in depth of shade, and the bright wall will also be darkened. The contrast is thus diminished and the crateriform character may be completely lost.

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[*] Translated by EDWARD S. HOLDEN.

[†] Most of the positive glass copies which have been sent to the Observatory of Prague from Mount Hamilton have been copied by *contact*. To avoid the errors which arise from imperfect contact, it is, I think, better to make such copies by means of a photographic lens and a camera.

In passing, it may be remarked that the crater to which I have referred is placed by SCHMIDT too far to the north, and is too small (nearly) by half. The following comparison of the drawing of *Langrenus* (which relates only to the more important features, however), refers to SCHMIDT'S large Moon-map of about 2 *meters* diameter. *Langrenus* is given at the southern border of SCHMIDT'S Section XI.

1. The system of rill-like objects in the southern interior portions of *Langrenus* is very noteworthy. Although they do not show separate walls, definitely illuminated, yet they agree well with the lunar surface and lie at right angles to the direction of the Sun's rays, and are therefore to be regarded as real objects. The most easterly part of the rill system which there avoids an elevation by a marked curvature can be perfectly well recognized on II.

2. In the interior, northwest of the central peaks, is a well-marked rill-valley, with crater-like branches and with bright walls on the side facing the Sun. The middle portion of this is also on II.

3. At the southwest end of the central peaks the photograph shows a large crateriform object, which is not represented in this way by SCHMIDT, who lays down two parallel ridges here.

This crater was seen by C. M. GAUDIBERT, in Vaison (Vaucluse), on August 29, 1893, with his reflecting telescope of $0^{m}.26$ aperture, who remarks as follows:

"On August 29, 1893, $12^{h}\ 45^{m}$ to $1^{h}\ 40^{m}$ A. M., I was observing *Langrenus* for the purpose of obtaining a view of the clefts shown by Mr. WEINEK on his beautiful drawing of this formation. I found that the Sun was still too high on that horizon to show those clefts; but the numerous cuttings along the inside of the southwest terrace, and the numerous ridges covering the south portion of the floor, made it very likely that under a lower Sun, when these ridges would cast their shadows, the scenery must be very much like the drawing of Mr. WEINEK. While I was looking carefully at the central mountain, I saw for the first time a crater on the southwest extremity of the top, and at once was impressed with the idea that this crater is easier than the one on the central mountain of *Capella*. Now, this crater had been discovered by Mr. WEINEK while enlarging the ring-plain *Langrenus*, and he had made known the fact in *Sirius*."—*English Mechanic and World of Science*, 1893, Dec. 1.

4. At the lowest margin of the picture, northwest of *Langrenus*, C, the photograph shows likewise a large crater, which is not given by SCHMIDT.

5. In this region, north of *Langrenus*, there is very much which is but poorly represented in SCHMIDT'S map. For instance, *Langrenus*, x and B, do not lie in the direction of the east wall of *Langrenus*, but at least the width of x east of it; and the position of these craters, *i. e.*, x and B, is too far north in SCHMIDT. On the other hand, C is represented too far south relatively to x and B.

The position of this crater in MAEDLER'S map is still more faulty. Other large errors of drawing are to be found in the relation of different sections of the wall of *Langrenus* to the central peaks.

In this respect it will be seen that alignments on SCHMIDT'S map will not always suffice even to identify the various features; and that the identification must be based upon objects whose form is so characteristic as to admit of no mistake. For instance, there is a long crater-valley westward from *x*, which is easily seen on the photograph. This leads toward the south to a bright eminence, this to the east wall of *Langrenus*, which extends southward in an undulating line, convex to the east, and there forms a peculiar notch, which we will call *e*. SCHMIDT shows a large crater east of this notch. Opposite to *e*, on the west wall of *Langrenus*, in about the same selenographic latitude, there is a cross-wall bending away (let us call it *q*), which is likewise plainly shown by SCHMIDT. If we join *e* and *q*, this line on the photograph goes nearly through the middle of the central peaks; whereas in SCHMIDT their whole mass lies to the south of *eq*.

6. The crater east of *e* is not clearly shown as such on the photograph, although farther to the east there is the fork-like division of the crests. Both branches of this fork on SCHMIDT'S map lead to the south, each to a large crater (call the western one *a*, the eastern *b*); these craters are likewise barely indicated on the photograph. It is most probable that their eastern walls are not very steep toward the interior, and that they would be better seen with an even lower altitude of the Sun; or else the exposure-time was not such as to bring out their true character. At the origin of the fork the photograph shows crateriform objects on both prongs, which are not given in SCHMIDT. In these regions east of *Langrenus*, between *e* and its south end, SCHMIDT gives a very great number of very small craters, arranged like a string of pearls, one following another. This arrangement (in the map) is too regular as to the size and the situation of the craters to be regarded as a true representation. The photograph shows no separate small craters; but their situation is very well marked by long valleys.

7. On the other hand, the photograph shows other very small craters with the greatest clearness; in particular, a very minute one on the middle of the west wall of *Langrenus* (lying in the shadow of an elevation), which has a diameter of only 1 *mm.* on the 20-fold enlargement, and therefore a real diameter of but 0.17 geographical mile. Similarly a very minute, well-defined crater, with its west wall illuminated, lies on the south wall of the crater *a*, before mentioned, and can be recognized, though unsatisfactorily, on II. On the other hand, the positive (I), when viewed by transmitted diffused light, shows on the north wall of *x* a specially clear, small crater, which I do not think is to be regarded as real (on account of its relatively great sharpness of outline), but which I have, nevertheless, included

in my drawing, which is intended to represent *everything* seen in the photographic plate. The conclusion that this object is in fact an error of the plate (a fine bubble in the surface of the glass having only 0.03 *mm.* diameter) is proved to be correct: *first*, by viewing the plate by means of an intense light *without* dispersion, moving the source of light sidewise; and *second*, by viewing it by means of a beam of oblique rays allowed to fall on the plate from the front side, while the plate is viewed in two positions differing 180°. Such tests would have been much easier to apply if the original negative from which I was made had been accessible to me.

8. To the south of x toward e, SCHMIDT has laid down a small crater, which is well marked on the photograph. Northwest of this the photograph shows a similar and slightly smaller crateriform object, which is not given by SCHMIDT.

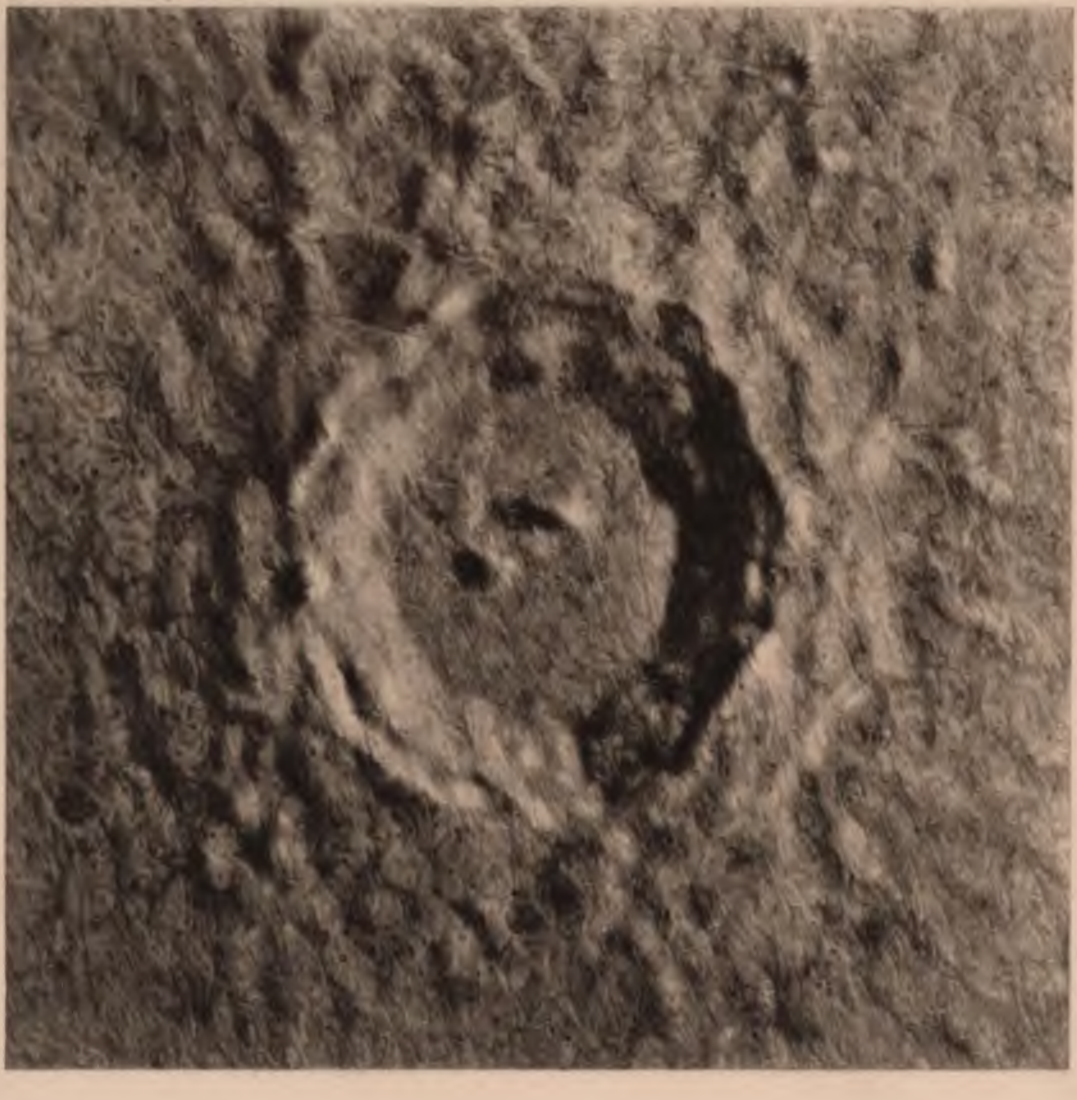
Also, there appear to be two crater depressions, near together, on the inner northwest wall of *Langrenus*, which are missing in SCHMIDT'S map.

The above remarks relate (only) to the most important of the details, which are shown by the photograph.

The accompanying heliogravure shows how rich this detail is.

The most interesting objects of those not previously known are the rill-like rifts. That they are real features of the surface is shown by the fact that they lie in general perpendicularly to the direction of the Sun's rays. This peculiarity has been observed on all the plates from which I have made drawings, and remains unchanged, no matter how the artificial illumination of the plates is varied, and no matter how the plate is oriented with respect to the vertical.

Even if these finest details of the plate are left out of consideration altogether (since in the most delicate details of photographs there must always remain room for some differences of interpretation, just as in visual observation the very finest details on the border of visibility are always more or less doubtful)—even if these be altogether disregarded, the drawing from the photographic plate reproduces the lunar surface in the neighborhood of *Langrenus* in a manner incomparably more true than does any existing lunar chart.



COPERNICUS.

DRAWING BY PROFESSOR L. WEINEK, ENLARGED TWENTY-FOLD

FROM THE NEGATIVE TAKEN AT THE LICK OBSERVATORY ON JULY 28, 1891, $15^h\ 49^m\ 16^s$ P. S. T.

DRAWING OF COPERNICUS.[*]

(See the heliogravure plate facing this page, and also the index-map.)

When I received from the Lick Observatory an extremely fine *dia-positive* of the Moon copied from a focal-negative made at Mount Hamilton, 1891, July 28, at $15^h\ 49^m\ 16^s$, P. S. T., it became possible for me to carry out a desire of long standing, namely, to make a true representation of the splendid ring-plain *Copernicus*. When I commenced the drawing, which is represented in the accompanying heliogravure in a 20-fold enlargement (14x14 *cm.* in size) from the original, the first glance showed me that the labor would be long and arduous on account of the immense number of details to be studied and adequately represented. I estimated at the beginning that some 200 hours of work would be required for the drawing which I had undertaken. My estimate was still too small, as in fact 224¾ hours have been spent on this plate. In order to make the enlarged drawing as complete as possible, I employed the method described in the *Prager Astronomischen Beobachtungen* of 1888–1891 (page 51), using a reticle of plane-parallel glass, ruled in small squares of ½ *mm.* on the side, laid over the *dia-positive*, while the plate was examined as a transparency. The corresponding squares of the enlarged drawing on paper were 10 *mm.* on a side, and the first process was to lay down the outlines of the figure accurately within these squares, and to put in the principal shadows of the manifold details with pencil. This work alone required 44½ hours. After this preliminary work was finished, the glass reticle was removed, and the various portions of the image were finished, step by step, by the brush and India ink. This second process required no less than 180¼ hours of work, so that the completed drawing represents the labor of 224¾ hours on 141 separate days, between January 4, 1893, and January 15, 1894.

Although the interpretation of the finest details (whose images are more or less influenced by the disturbing effect of the grains of the emulsion-plate which was employed) is in many cases quite difficult, I believe that the very long time spent in my study of this fine *dia-positive*, under many different illuminations, has resulted in making the completed drawing very accurate in its general effect and in its minor detail. Whatever errors it may still contain—and I believe they are very few indeed—are obviously not to be found out by a casual inspection, but will demand for their detection a labor at least comparable with my own. And the same remark applies to all the drawings given in this book.

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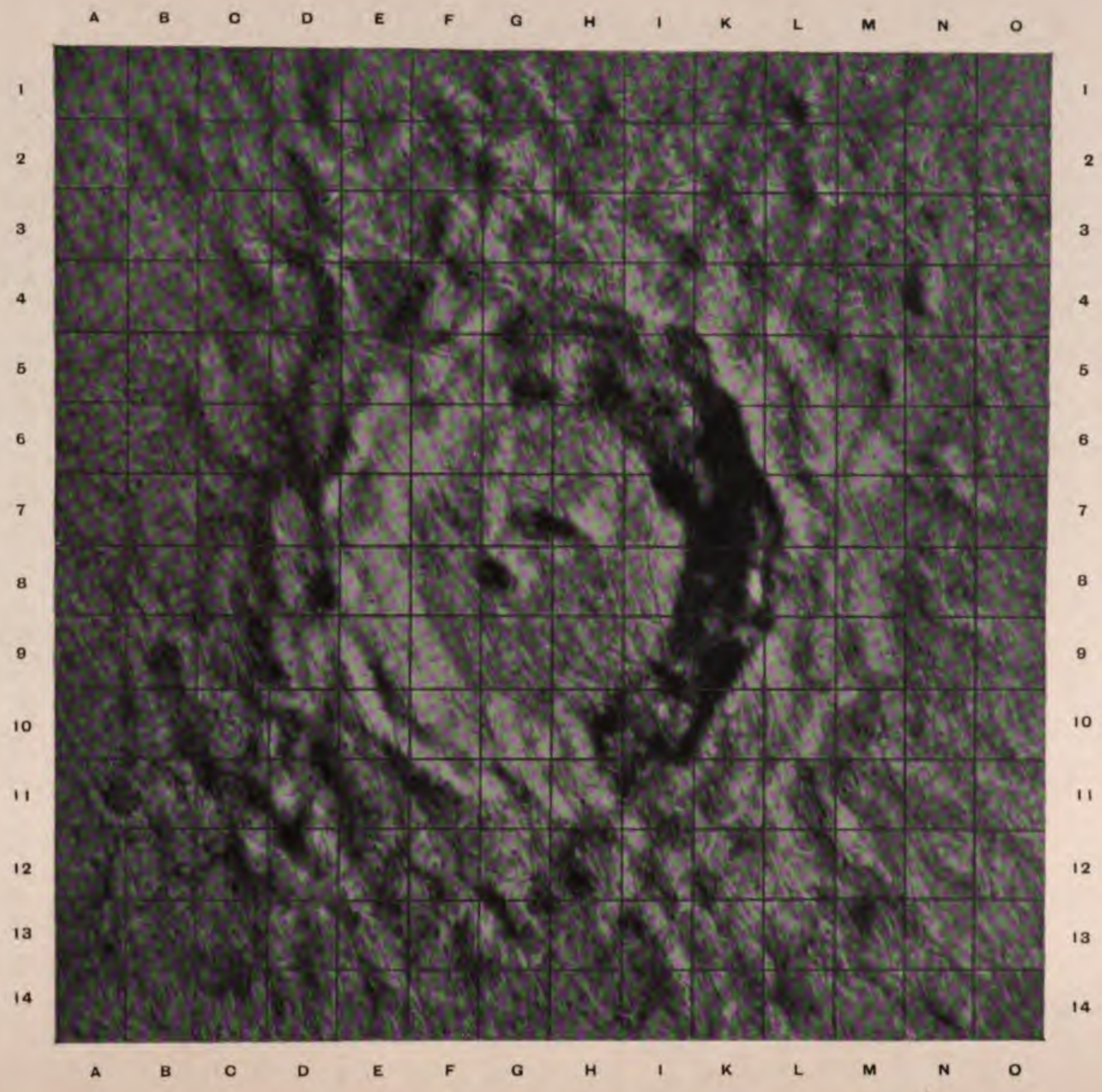
[*] Translated by EDWARD S. HOLDEN.

I do not doubt that the original negative, preserved at the Lick Observatory, would have been even more suitable for my work than the *dia-positive* actually employed. The heliogravure reproduction of my drawing was made by the *k. u. k. Militär-geographisches Institut* in Vienna, and is a masterly piece of work; although it must be noted that somewhat of the softest detail is lost, and that the left hand upper corner of the plate is somewhat too light in tone. In order to facilitate the description of the detail of this plate, the heliogravure is accompanied by an index plate on the same scale, containing the lines of my original enlarged reticle. The horizontal intervals of the reticle are marked with letters, and the vertical intervals with numbers, so that the description of the different parts of the plate can be made by rectilinear coördinates, as on a chess-board.

A first glance at the rich and extremely complex structure of the image makes it obvious that no artist's drawing at the telescope after nature can ever produce an entirely satisfactory representation of so complicated an object as this crater. The artist at the telescope requires more and more time to represent a lunar landscape the more complicated the landscape is. While his work is going on the shadows are progressively changing, and with the change of shadows the whole aspect of the region alters. There is therefore no resource remaining for him but to base his representation upon several rapid drawings or sketches secured on various evenings. This necessity, combined with the lack of artistic skill too often noticeable in the work of observers of the Moon, is sufficient to account for the serious errors which often remain in the representations of lunar landscapes. Photography, on the other hand, builds up the whole image in a few seconds with entire accuracy. A fully objective representation, corresponding exactly with the lunar surface, would be obtained were it not that many separate objects of the same region require different exposure-times. On this account only portions of the image of any one negative are correctly depicted; the others are either over- or under-exposed, and show variations in visibility, which are sometimes taken, by those who have not reflected on such matters, to be defects inherent in the photographic method; whereas they are rather consequences of the extreme sensibility of the photographs to the smallest variations in the color and in the light of the object depicted.

If *several* negatives of the same landscape are taken, one after another, and if the exposure-times are somewhat varied, a series of images is obtained, which, taken together, show the landscape far better than it can be depicted by any artist



INDEX MAP.—COPERNICUS

copying it directly after nature. Among the published drawings of this ring-plain by Lohrmann, Maedler, Schmidt, Neison, and Secchi, that of Schmidt agrees much the best with the photographs, although even this drawing is susceptible of many improvements.

Schmidt's remarks upon *Copernicus*, and upon the drawings of Lohrmann and Maedler, are as follows (see *Charte der Gebirge des Mondes*, Berlin, 1878):

"1851, February 10. The principal wall is, on the whole, very nearly circular, and the variations from this form lie chiefly in the east wall. Maedler has much distorted this magnificent crater in his map. Lohrmann has drawn it somewhat better. My own representation is also not satisfactory, since it is too uniform, and the fore-shortening is not sufficiently attended to."

It is to be noted, however, that Lohrmann has depicted the three central mountains fully in agreement with the photographs, and the westernmost of these is better drawn by him than by Schmidt.

Secchi's drawing (in *Le Soleil*, part II, page 403, Paris, 1877; also, in *Memoirs* R. A. S., vol. 32, plate VIII) is too conventional a representation to have much weight. Neison's special map of *Copernicus* in his Moon atlas is defective in several respects. Various careful drawings of *Copernicus* have been made by the skillful French selenographer, C. M. Gaudibert, of which that of 1890, June 27, may be considered as one of the most successful, and of great value, as is to be expected of the work of this observer.

In order to compare these different drawings with the photographic representations in as thorough a manner as possible, I have employed not only the *diapositive* before mentioned, but also six negatives, which have been presented to the Observatory of Prague by the Lick Observatory. The following little table gives the nomenclature employed in the discussion. The words *ante* and *post* in the fourth column mean before and after full Moon. The last column gives the approximate altitude of the Sun as seen from *Copernicus*.

No.	Plate.	Date. h. m. s.	Age.	Situation of the Terminator.	Altitude of the Sun.
I.	Dia-positive	1891, July 28, 15 49 16 . .	post	Through *Stadius* and *Pitatus* .	6°
II.	Negative. .	1891, July 28, 14 51 5.5 . .	post	Through *Stadius* and *Pitatus* .	6°
III.	Negative. .	1891, Oct. 12, 7 29 9 . . .	ante	At *Agatharchides*.	12°
IV.	Negative. .	1891, Oct. 12, 7 30 54.5 .	ante	At *Agatharchides*.	12°
V.	Negative. .	1893, July 23, 8 27 53.2 .	ante	At *Encke*	17°
VI.	Negative. .	1892, Nov. 10, 14 54 31 . .	post	On the west wall of *Albategnius* .	26°
VII.	Negative. .	1892, Nov. 10, 15 52 41 . .	post	On the west wall of *Albategnius* .	26°

In order to effect a convenient and exact comparison between my 20-fold drawing and the other drawings above named, I have made, with the assistance of

Dr. SPITALER, a 24-fold enlarged *dia-positive* from each of the negatives II–VII, and have examined these positives, which completely represent their originals, as transparencies.

It is to be remarked that II is not of much value for the finer detail, since it is considerably fogged, while, on the other hand, VI and VII show *Copernicus* too far from the terminator, and for that reason it is much over-exposed. This does not prevent certain darkly shaded objects near *Copernicus* from being rightly exposed. Nos. III and IV are the best plates.

Let us now proceed to the discussion of the *Copernicus* heliogravure, which we may treat in three sections: (1) The interior floor of the crater; (2) the inner walls; and (3) the outer walls and their surroundings.

The orientation of the plate rests on the following considerations: To the south of *Copernicus* lies the well-known double crater, whose northern component is called A. I shall call it A (*Cop.*). It is drawn on Section VI of SCHMIDT'S map, and is to be found in my drawing in the square (F,–1). North of *Copernicus*, SCHMIDT has drawn on his Section V a prominent crater, marked A, which is connected with *Gay-Lussac* on the south, and which I shall call, for shortness, A (*Gay*). It lies in my drawing symmetrically on the line which divides the squares K, 15, and K, 16. If we join the center of A (*Cop.*) with the center of A (*Gay*), this line passes in SCHMIDT'S map through the eastern half of *Copernicus* (distant about one-sixth of the crater's diameter from its middle point), while on all the photographs, I to VII, it passes close to the center of *Copernicus*, and a very little east of it.

According to SCHMIDT, the meridian through the center of *Copernicus* makes an angle of 9° with this line, so that its direction lies west of A (*Cop.*) and east of A (*Gay*). The center of *Copernicus* corresponds accurately with the middle point of the net-work of squares. In the drawing, the meridian line joins the intersection of D and E with the upper edge of the picture to the intersection between K and L at the lower edge, and makes an angle of 23½° with the middle vertical line of the reticle, very approximately.

THE INNER CRATER FLOOR.

SCHMIDT speaks of it thus: "1846, July 3, at Bonn, with the 5-foot refractor, I saw in the interior area of *Copernicus* 24 hills, including the central mountains;" and again, "1853, May 17, I drew a part of the ring-wall of *Copernicus* with the Berlin refractor. The interior area is by no means a plane surface." The last remark is fully confirmed by the photographs. There are three central peaks. The eastern one lies in H, 7, and I have called it *a*; the western in G, 8, and I have called it *b*; for clearness in the description. The middlemost peak between *a* and *b* is the lowest. SCHMIDT draws *b* as a rounded conical mountain, whereas it has in fact a more nearly triangular cross-section, and it stretches farther to the south than he has drawn it. LOHRMANN'S representation of these three peaks agrees well with the photographs.

1. According to I, the peak *a* seems to have three to four small craters on its southern crest, of which the heliogravure (H) shows only two. At its southeasterly foot (in the right hand upper corner of G, 7) lies a rill-center, or crossing point, from which two rills can be traced toward the crest of *a*. The most western rill is still further prolonged on the other side of the mountain, through the southern part of the middle hill, and it appears to pass through two small crater formations. Plate III confirms the above description concerning the western rill.

2. On March 30, 1890, M. GAUDIBERT discovered a small crater on the northern border of peak *b*. According to a sketch of June 27, 1890, which he kindly sent me, this crater lies in the western part of the northern border. It appears to be identical with the small dark object to be seen in the left hand lower half of G, 8, from which a kind of rill, or crack, extends toward the south in the mountain. GAUDIBERT'S drawing also contained this rill. GAUDIBERT'S crater, just described, is to be seen on III and IV; on III, with a shadow to the west in its interior; on IV, as a circular outline. The cleft extending to the south is visible on both plates. Plate IV also shows a rill extending from this crater toward the northwest as a continuation of the southern rill, another toward the northeast, and still another short rill toward the southeast. Plate IV shows the crater to be 1.27 *km*. in diameter, which agrees very well with the sketch of GAUDIBERT. GAUDIBERT has drawn this peak, *b*, as a nearly isosceles triangle, whose base is the north border, of which we have spoken, which lies in the direction east-west, and which is shorter than either of the other legs of the triangle. All the photographs confirm this description in a general way. Some of them show very plainly, however, that the northern part of this mountain is a decided cone, whose slope seems to be terraced. These rounded terrace lines are well seen on I. III, on the other hand, shows the somewhat oval base line of the cone most satisfactorily. On the western slopes there is a small crater (on I), from which the rill before mentioned extends to GAUDIBERT'S crater. From the small crater (on I) there is yet another rill-like trace extending toward the west to the wall of *Copernicus*. This is not shown on H; it is very well seen on II; not so well on III. Still a third rill extends toward the south from this crater, and according to II, another toward the east. It appears that this crater was a center of active forces. Upon the summit of *b*, I shows a small crater (not obvious on H, somewhat to the left and above the middle of the square G, 8), which has a narrow rill extending to the southeast. II, III, IV, and V also show this crater, which is best seen on IV.

Although the interpretation of an object so small as this, which has a diameter not over 0.7 *km.* (though this diameter is still some ten times larger than the grain of the plate), is beset with some uncertainty, it is yet extremely probable that the mountain *b* has a summit-crater, and for that reason it is desirable that this point should be examined optically with a large telescope. The photographs also seem to indicate the presence of two or three lateral craters also.

3. From the southern part of the mountain *b*, there is (according to I) a low, broad, elevation, extending toward the southeast throughout the entire southern interior of *Copernicus*. This lies on the left hand borders of the squares G, 7, and G, 6. LOHRMANN has drawn its more northerly part.

4. A distinct rill-formation extends (according to I) from the inner southwest wall of *Copernicus*, passing, in F, 7, almost north and south, directly to the peak *b*. On II this rill is seen still further on the eastern border of the peak, up to the dark area in the lower central part of the square H, 8. On the plates taken in the first half of the lunation this long rill is still to be seen, though with difficulty.

5. The well-marked crater north of the peak *a* in H, 8, with a very small crater in its center, is of especial interest. The diameter of the principal crater is 2.2 *km.* Several fine rills have their terminations within this crater. On its southwest border there appear to be one or two extremely small craters. Plate III shows this crater almost as well as I, although the illumination is directly opposite in the two plates. It appears on III as a round, sharply limited, dark object, in the right position and of the appropriate magnitude. In III there is shown, without doubt, a small crater on the southwest border. Plate II shows also the larger crater with considerable certainty. East of this last mentioned crater, I displays a somewhat smaller crater-pit, and to the southeast (in the right hand upper corner of H, 8) there appears to be still another similar, though larger, crater-pit. To the west there is a short, very sharply marked rill, with its west wall bright. In the western and northern neighborhood of this rill there are five very minute craters, with diameters of about 0.5 to 0.6 *km.*

6. In the right hand upper corner of G, 10, on the north border of the interior of *Copernicus*, there is a crater somewhat larger than those just named. SCHMIDT gives this object, as does NEISON also, and it is especially plain in the special chart of the latter observer.

N. B.—It is to be remarked here that there is a sharp, dark, point in the heliogravure, north of the object just described, and at a distance of one of its diameters. This is a defect in the heliogravure, and not a feature of the Moon.

7. A crater of the same order as the two last named appears to be situated on the northwest border of the interior in F, 9, according to I; but it is barely visible in the heliogravure.

8. In the upper central part of H, 10, there is a very small crater, with a similar one lying somewhat to the north of it. The latter is barely indicated on the heliogravure. The two are, in all probability, identical with two craters observed by GAUDIBERT, in this place, on June 27, 1890. Similar small craters, down to a diameter of 0.38 *km.*, are to be seen in G, 6; H, 6; F, 7; G, 7; H, 7; J, 7 (in this square is one on the border of the shadow, which is not plainly shown in the heliogravure); in F, 8; H, 8 (already mentioned); in J, 8; G, 9; J, 9 (in this square there is a group of three craters in the right hand central part of the shadow of the wall, which is not easy to see in the heliogravure); in H, 10 (already mentioned); and, generally, such craters are to be found in nearly every square.

9. Rill-formations are to be seen, especially in H, 6; F, 7 (already mentioned); F, 8; F, 9; G, 9 (in the form of a cross of St. Andrew); G, 10. In J, 8, the long trace there seen is probably the shadow of a very low elevation. On the other hand, there is here to be found on the right-hand edge of the square in the shadow of the wall, a very striking rill (or cleft), with well-marked, bright, western walls.

THE INTERIOR WALL.

10. On the interior west wall there is a crater, which is very easily seen in the telescope, and which SCHMIDT characterized as follows on August 21, 1866, as he was observing with the 6-foot refractor at Athens: "On the interior west terrace of *Copernicus* there lies a very well-marked small crater at the eastern foot of the high wall, which is at least 1200 *toise* lower than the summit of this wall." This crater is barely indicated in E, 8, owing to over-exposure of the very bright wall, but its outline is pretty well shown on plate II. There is no doubt that a suitable exposure would bring this crater out with all desired sharpness. Plate IV shows connected to it toward the north a very plain, large, round formation, 3.4 *km.* in diameter, with bright wall outlines, and with a floor which appears somewhat convex. In its center is a very small crater, which is, no doubt, identical with the very small crater in the lower middle part of E, 8. Plate V also shows the last-named object.

11. Upon the inner north wall SCHMIDT lays down a rill, which he discovered March 27, 1855, at Rome with the 14-foot refractor of the Observatory of the *Collegio Romano*, and which he verified July 6, 1862, at Athens. NEISON doubts its rill character. This rill is plainly visible in J, 10, and it lies nearly in the meridian. Plate I seems also to indicate several branches to this rill.

12. At the northern end, in the lower central part of J, 10, there is a large crater-formation; and another west of the rill in the right hand middle part of H, 10; as well as a smaller crater on the right hand upper margin of H, 11.

13. Other wall-rills are to be found, especially in F, 10, and G, 10; in E, 10, where the rill cuts through the crest; in E, 7, where the course of the rill is toward the right hand lower corner, where it pierces a large oval formation, which looks like a low conical mountain; in F, 5, and G, 4, where the crest is prominently intersected; in K, 5 (at the crest with a small crater); in J, 6, on the bright terrace, and in J, 7, in the shadow, east of the small crater there situated.

14. Small wall-craters are likewise abundant, particularly on the south and southeast wall. In the latter situation they are especially well marked in H, 5, J, 5, and J, 6.

15. On the southern crest, in the upper margin of F, 5, there is seen a large, round object, with two outer rings and one inner ring, which appears to be the connection of a conical formation with a central crater. This can be made out on II, III, IV, also. The last two plates confirm the impression from plate I, although the object is quite dark on the former plates. III and IV show various rills which stream from the center. One of these, which runs toward the northeast, is visible on I.

16. North of these formations, on the interior walls, lie the so-called *dark points*, which do not vanish as the Sun's altitude increases, but sometimes first become easily visible under such conditions. These were first discovered by SCHMIDT, and have been often observed subsequently by KLEIN and others. SCHMIDT first speaks of them on January 16, 1851, during his observations with the 5-foot refractor of Bonn. On this day he writes: "In the south wall of *Copernicus* there are two small dark spots; the eastern one is the larger. The shadow had long since vanished." Similar notes were made on the 13th and 14th of February, when he remarks that both areas are dark gray, and on the 15th of February, when he mentions having seen three other small areas near the two first discovered. These spots are not laid down in SCHMIDT'S chart. They are to be found, however, in KLEIN'S *Fuehrer am Sternenhimmel*, p. 323, where the two most noteworthy are drawn in a small chart of *Copernicus*, which is a copy of NEISON'S chart.

At the same page KLEIN gives a summary of his observations. The easternmost of the two first-named areas is comparable in magnitude, according to KLEIN, with the inner dimensions of the crater *m*, which lies outside of *Copernicus* and southwest of it. This crater *m* will be described in what is to follow, and its diameter is at least 3 *km*. For this reason the frequently-used expression, "dark point," can only be appropriately employed to describe its appearance in small telescopes. So far as can be made out from the small drawing of KLEIN, the eastern spot lies in the line which joins the center of *Copernicus* and the west wall of A (*Cop.*), while the western spot is about one diameter of A (*Cop.*) distant from it. The middle of the latter spot should coincide, therefore, with the small crater in the right hand lower corner of F, 5, although no dark *nimbus* is seen in this place. The first is to be sought for in the square G, 5. On III, and especially on IV, the western dark spot is easily seen. According to IV, which shows this neighborhood very sharply defined, a small dark crater of 1.0 *km.* in diameter lies somewhat to the south of the middle of the *nimbus*. From this crater four well-marked rills radiate. The dark crater, which appears to be identical in position and magnitude with that in F, 5, is surrounded by two concentric circles, of 2.6 *km.* and 4.8 *km.* diameters, respectively. The entire object is, if we may judge by the shadow, a low, dark, conical hill, on whose summit is placed the crater of which we have just spoken. Plate IV shows to the southeast and east of this crater, particularly toward the southeast, about 11 *km.* distant, eight similar dark craters, whose diameters range from 0.4 to 1.0 *km.* Through some of these, rills are seen to pass. A similar dark crater, of 1 *km.* in diameter, is to be found half way up the inner north wall of *Copernicus*, somewhat to the west of SCHMIDT'S rill, yet without a dark *nimbus*. The eastern dark spot is especially well seen on VI. It bears in its center a minute crater, 0.4 *km.* in diameter, with a ring of 1.0 *km.* in diameter about it, besides two further concentric rings of 3.7 and 6.4 *km.* The dark *nimbus* extends beyond these latter rings. The eastern spot appears to be larger than the western. According to IV and VI the places of the centers of the two spots are as follows: The western lies in the line joining the center of the peak *b* with the west wall of A (*Cop.*), while the eastern is upon the line joining the center of the peak *a* with the center of A (*Cop.*).

THE OUTER WALL AND THE SURROUNDINGS.

We must now speak of two well-known dark craters, which are to be found in the drawing. The first of these lies to the southwest of *Copernicus*, somewhat less distant than A (*Cop.*), and called *m;* the second lies to the north, near A (*Gay*), and is called *n*. Both have been drawn and described by KLEIN (*op. cit.*, pp. 323, 324).

17. The crater *m* is drawn on SCHMIDT'S map, Section VI, west of A (*Cop.*), and is easily recognized by its darkly shaded *nimbus*. SCHMIDT refers to it first on February 15, 1851, when he says that he has seen (in Bonn) "to the southwest (of *Copernicus*), in the direction of *Gambart*, a bright point surrounded by a dark gray *nimbus*, which itself lies on a gray plain." And again on April 10, 1873 (in Athens), "the gray spot between *Copernicus* and *Gambart*, called *m*, has a white center, which has been previously recognized as a crater." My drawing shows *m*, undoubtedly, in the right hand lower corner of B, 2, although its crateriform character is not entirely indicated on I. Its true place can be recognized partly from the mountain chains which lead to this crater, partly from the plates III, IV, and V,

in which the shadows are thrown in the contrary direction, and where the crater character is very plainly indicated. They can be readily compared by using the negatives of the first quarter with the positives of the last quarter. This device was also employed in the drawings of *Arzachel*. III, IV, V show *m* to be almost equally conspicuous with the crater B, southwest of *Copernicus*, in the square L, 1. Its diameter is from 0.5 to 0.7 of that of B. I shows in the neighborhood of *m* very many small craters. The best seen is one to the east, and on the left hand margin of C, 2; and two others to the south, near the center of B, 2. From the eastern small crater just named, I shows a fine rill extending toward the small dark crater on the right hand upper edge of C, 2, from thence turning toward the center of D, 1 (somewhat below the center), and finally reaching toward the center of the crater A (*Cop.*) This rill is unfortunately not shown in the heliogravure. In the western end, where it joins *m*, it is identical with the rill drawn by KLEIN. It should here be remarked that (on I) west of the small crater, on the right hand upper margin of C, 2, between this and the elevation in the center of the same square, there is still another small crater lying in the course of a rill, which is likewise missing in the heliogravure. The whole course of the rill between *m* and A (*Cop.*) is especially conspicuous on plate IV. West of *m*, KLEIN has drawn a terrace line, also in the prolongation of the eastern rill, whose course can be traced in B, 2, and B, 3, and which can be followed much farther on the *dia-positive* I. According to I and IV another rill extends from *m* toward the north, and, according to IV, yet another toward the south, so that *m* lies at the junction of three or four rills. From the small crater to the east a long crooked rill runs through the squares C, 2; C, 3; D, 3, to D, 4, where it debouches in a small crater formation. South of *m* lies in B, 2, an elevation in the direction west to east, whose course can be followed on the *dia-positive* I through the center of C, 1, although its latter part is lost in the reproduction. The dark *nimbus* around *m* is very strongly visible on plates III, IV, V, VI, and VII.

18. The dark crater *n* is to be found on SCHMIDT'S map; it is neither made prominent (not by any means as prominent as the crater *m*) nor is it designated by its appropriate letter (*n*). SCHMIDT speaks of its situation (1868, July 10), and says a strong blackish-gray spot lies north of *Copernicus* "in the direction toward *Gay-Lussac*"; and again on 1873, April 10, he describes it as "to the south, near *Gay-Lussac*." KLEIN writes (*op. cit.*, p. 324): "The crater *n* is larger (than *m*), and its gray ring is more easily seen." In his chart KLEIN has drawn this crater very plainly, whereas NEISON has simply placed an *n* in its situation without drawing the crater itself. According to the descriptions given by SCHMIDT and NEISON the crater *n* of KLEIN'S chart is placed considerably too far to the east. All the photographs III–VII confirm the descriptions of SCHMIDT and NEISON. On KLEIN'S chart the

distance *n* to A (*Gay*) is equal to the distance *m* to A (*Cop.*). Whereas, the latter distance is in fact 2½ times larger, and consequently *n* is to be placed much nearer to A (*Gay*) than on the chart. The photographs of the first quarter of the Moon confirm this correction. To the southeast and near to A (*Gay*) there is a large oval, trough-shaped cavity (exactly as laid down on SCHMIDT'S chart), whose walls must be very low. It recalls the cup-shaped cavity in the interior of *Ptolemy*, north of crater A. This formation is not given by NEISON and KLEIN. Plates III, IV, V plainly indicate its trough-like character by its shadows, which are darker than its surroundings, and more intense on the west. There is a crater at its south end, as SCHMIDT gives it, which is, however, somewhat smaller than *m* and not so deep, and, therefore, less obvious. Plate IV shows this crater best (III and V not so well), and it must be the crater *n*, as is confirmed by the circumstance that its position is the center of the large dark *nimbus* when the Sun is high (as is proved by plates VI and VII). Measures on VI and VII on the one hand, and again on IV, give for the angle between *Gay-Lussac* (center), A (*Gay*) and *n* the same angle, namely, 112°.

According to the foregoing data we must look for *n* in the left hand lower corner of L, 13, where a sharp line of division between light and shadow passes through the crater. At first I was disposed to consider the dark crater on the upper edge of M, 13, as *n*, assuming the correctness of KLEIN'S drawing. This identification cannot be correct, as the photographs taken with a high altitude of the Sun plainly show. The crater in M, 13, is also given by SCHMIDT without any special relief. Plate VI shows it to have also a dark *nimbus* which is only one-third as large as that about *n*. The latter is about as large as the crater A (*Gay*).

19. Professor HOLDEN, in the year 1890,* in studying the Mount Hamilton negatives, found a large ancient crater-ring of oval form joining *Copernicus* toward the southeast, which is best seen on Moon negatives taken when the Sun is at a high altitude; such a negative, for example, as that of 1890, October 27. Plate I shows this crater-ring fairly well when one knows where to look for it. It is difficult to make out on the heliogravure, in which only the western and less obvious part of the ring is to be seen. According to the plate of the full Moon, above named, the ring goes through the squares H, 3; H, 2; H, 1; thence in an arc south and east to the crater B (in L, 1), and traverses the squares N, 1; N, 2; N, 3; N, 4 (where the mountain there situated forms a part of the ring), and ends in M, 5, at the outer wall of *Copernicus*. The center of this ring lies somewhat to the west of crater B, and falls in K, 2.

20. The crater B, to the southeast of *Copernicus*, is placed by NEISON and KLEIN too far to the east. It is, in fact, situated so that the line which joins it to

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A (*Gay*) is very nearly tangent to the eastern crest of *Copernicus*. Neison and Klein also show, between B and A (*Cop.*) (somewhat nearer to B than A), a crater of the same dimensions as B. Schmidt does not give this crater, and it is not shown on any of the Lick plates.

Schmidt lays down a crater north of A (*Cop.*) of about the same dimensions as *m*. The heliogravure shows this on the left hand middle border of G, 1; it is better seen on III and IV, and most plainly on V. Gaudibert observed this crater on March 26, 1885. It is not given by Neison or Klein.

21. A long and fine rill-formation on I is especially noteworthy. It traverses the crater B in a northeast and southwest direction, and passes through the squares N, 3; N, 2; M, 2; L, 2; K, 1 (here it is broad and resembles a valley), and J, 1. Plate III shows it to extend as far as the center of A (*Cop.*), and it is very brilliant on this plate, especially outside of the east wall of A. A branch nearly perpendicular to it, which is sometimes like an elevation and sometimes like a rill, goes from B through K, 2; K, 3, and J, 4, as far as the southeast crest of *Copernicus*, and through L, 1, to the opposite side of B. B therefore is, according to I, the crossing point of four well-marked rills.

In what relates to the more distant surroundings of *Copernicus*, the heliogravure speaks for itself. There is scarcely a square which does not contain a small crater or a rill-like trace. These rills lie, nearly always, at right angles to the direction of the Sun's rays, which fact is an important witness to their reality as veritable rills on the Moon. Schmidt has expressed himself as follows (Athens, 1867, January 14): "In the west wall of *Copernicus*, on the terminator, every valley, every cavity, seems to contain rills or crater-forms." The drawing shows that this description is true for the entire wall. In what follows I have collected references to the most important, or to the most obvious of such formations.

22. *Small craters* are to be found in the following situations (writing them in the direction of horizontal lines in the heliogravure):

C, 1; E, 1 (with radiating rills); H, 1.

E, 2; F, 2 (many small craters); H, 2; K, 2 (with radiating rills); M, 2; N, 2; O, 2 (a large, shallow object, with a central point, and farther to the north a small crater with radiating streams).

D, 3 (small craters connected with rills); J, 3 (large object in the right hand lower corner); L, 3 (large, oval, crater-like object on the upper border).

C, 4; E, 4; F, 4 (the reference is particularly to a large object, in the upper central portions, which extends into the square F, 3. Plates III and IV prove it to be a crater, and plate IV shows its diameter to be 2.3 *km*. It is not so well seen on plate I); G, 4 (two small craters on the crest; the easternmost is especially plain on I).

C, 5; L, 5 (with radiating streams); O, 5 (very obvious, with radiating rills, and lying in a large depression).

A, 6 (with rays); C, 6; D, 6; L, 6 (large, ring-shaped formations, and two small craters, with a rill joining them).

A, 7; B, 7; C, 7; L, 7 (with rill-streams); M, 7 (several very small craters); O, 7 (a small crater with rays, which seems to be a conical mountain).

C, 8 (two large craters, the easternmost is especially plain); L, 8 (on the crest of *Copernicus*, and to the east of it).

B, 9 (large object); L, 9 (very small craters); M, 9; N, 9.

C, 10 (an obvious crater with rays, which seems to lie on a conical mountain, but which is not well shown in the heliogravure. In the right hand lower corner there is still another small crater, lying in the midst of a larger one. The latter is much better seen on II than on I); E, 10; M, 10; N, 10; O, 10.

A, B, 11 (large crater-like object, with rills debouching in its interior, and with small craters within it); C, 11 (large ring-shaped object); D, 11; F, 11; J, 11; K, 11; L, 11 (large object with rill); N, 11.

C, 12; E, 12; F, 12; G, 12 (very small crater with rill-rays); J, 12; N, 12 (plain); O, 12 (plain, with indications of a wall).

A, 13 (large object); E, 13 (plain); H, J, 13; M, 13 (dark crater with rills).

E, 14; H, 14 (a plain, small crater in the course of a rill, and other craters).

23. Among the *rill-like formations* the following may be cited:

E, 1, 2 (connected with craters). D, 3; K, 3; M, 3 (with bright walls).

E, 4 (connected with craters); F, G, 4 (with bright wall on the crest of *Copernicus;* its course can be followed up to E, 3; it is plainly visible on plate III also); H, 4, 5 (several rills crossing the crest).

E, F, 5 (this rill is particularly interesting; it seems to be a kind of a pass in the south wall. It can be seen in plates III and IV also. On IV it extends further to G, 5, where it forms an arc in the left hand lower corner of that square, and from thence it traverses the entire southwestern portions of the interior of *Copernicus* until it enters the square F, 8; from G, 5, to the middle of F, 7, it has a plain, bright wall on the side turned away from the Sun); O, 5 (with bright wall and a small crater).

D, 6; L, 5, 6; M, 6; N, 6.

A, 7; D, 7 (strongly marked); L, 7; M, 7 (clear); N, 7 (clear).

C, 8 (connected with craters); M, 8; N, 8.

B, 9; C, 9 (strongly marked); D, E, 9 and 10 (evident on the northwest crest of *Copernicus*); M, 9 (passes through a small crater); N, 9.

C, 10; K, 10 (with bright wall); M, 10 (connected with small craters); N, 10 (clear); O, 10.

A, 11; B, 11; C, 11; E, 11; F, 11 (on the crest, with bright wall); G, 11; L, 11 (connected with a crater); M, 11; O, 11.

C, 12; D, 12; E, 12; F, 12 (clear); G, 12; H, 12; J, 12; L, 12; M, 12 (clear); N, 12; O, 12.

B, 13 (strong, with bright wall); C, 13; E, 13; G, 13; J, 13; K, 13; L, 13 (strongly marked); M, 13; N, 13.

B, 14; E, 14 (connected with a crater); F, 14; G, H, 14 (clear); J, 14; L, 14 (strong); N, 14; O, 14.

24. I wish to call particular attention to a large three-cornered valley in E, 4, where two mountain ridges meet. These ridges lead toward A (*Cop.*). The valley is enclosed on the southeast and northwest by two interesting rills, or elevated ridges, and appears to have a steep declivity toward the northwest. The inclined surface of the valley shows several small craters and rills.

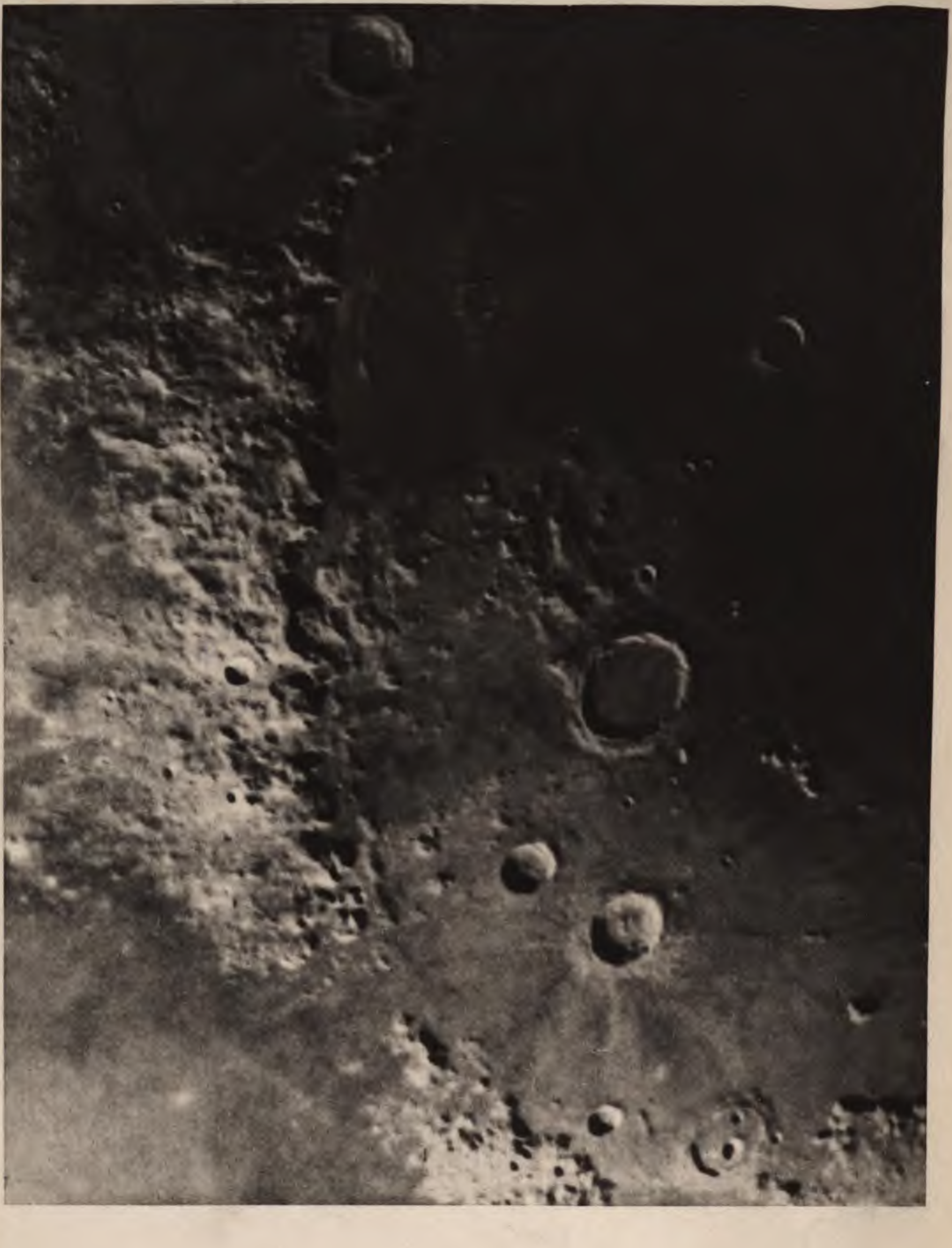
Outside of the southeast wall of *Copernicus*, SCHMIDT has drawn a crater in the form of an Arabic numeral 8, which is not given by MAEDLER and NEISON. It is identical with the large object in the corners of the four squares G, 2; H, 2; and G, 3; H, 3.

The very obvious, though rather shallow, crater-like object in A, B, 11, whose border appears to be a crown of small craters, is not laid down by SCHMIDT. It can be verified with some difficulty on the plates corresponding to the Moon's first quarter.

I have limited the foregoing discussion of the drawing of *Copernicus* to the most important features only of this complicated and splendid region. Although the discussion is by no means a complete account, it is sufficiently full to show that the Mount Hamilton negatives constitute a veritable treasure for science, and that when they are studied with sufficient attention they will yield important additions to our knowledge of the details of the lunar topography. A complete acquaintance with such details is the only basis upon which we can safely found our views of the nature of the processes and forces by which this topography was moulded.

L. WEINEK.

Prague, 1894, April 1.



COPY OF AN ENLARGED NEGATIVE OF THE LUNAR APENNINES,

MADE AT THE LICK OBSERVATORY, 1891 JULY 14, AT $8^h\,12^m\,26.5^s$ P.S.T.

PHOTOGRAPHIC ENLARGEMENT OF THE LUNAR APENNINES.*

(See the heliogravure plate facing this page, and also the index-map.)

The plate represents chiefly the lunar *Apennines* in their eastern, central, and western portions, and extends from *Eratosthenes* to *Cassini*. It is a reproduction by heliogravure (by the k. u. k. Militär-geographisches Institut in Wien) of a 7-fold enlargement, by Mr. A. L. COLTON, from the excellent negative taken at the Lick Observatory, 1891, July 14, 8^h 12^m $26^s.5$, P. S. T., and it is on the same scale as the charts of LOHRMANN and MAEDLER. The picture corresponds to an age of the Moon of 9 days 0.2 hours, and thus to one day after the first quarter. The terminator falls on the west walls of *Tycho* and *Timocharis*. A glance at this lunar picture shows that in beauty, in plastic effect, and in truth to nature, it far excels all previous representations of the same landscape. Although the best drawings, such as those of LOHRMANN, MAEDLER, and SCHMIDT, testify to marvelous industry, yet each one of them is lacking in the unity which can only be attained by making a complete picture at a single sitting. The extreme complexity of the grotesque arrangements of the mountain masses makes it absolutely necessary for the artist to represent only small areas at one time; and subsequently to fit together, like a mosaic, the separate pieces. The photograph, on the other hand, does all its work at one time. It possesses another advantage, since the plate appears to be more sensitive to the finest gradations of light and shade than the eye, especially when the eye is tired and confused in the presence of a brilliant field, as is the case in lunar observations.

MAEDLER refers to the extreme difficulty of making a representation of the *Apennines* in the following words (*Der Mond*, page 242): "LOHRMANN, who appreciated the immense difficulty of representing this region of the Moon, began his first trials here, and has exhibited (the *Apennine* range) on Section IV of his map, with its contours, very near to the truth. The only thing that is not as it should be in his drawing is the monotonous character of the northern border. The multitude of mountain summits, single peaks, and hills which cover the high region is almost countless, and even the highest optical power and the most indomitable industry cannot succeed in representing all the details of this region, as they can be represented in the *seas*, for example. Our chart contains, to the west of *Conon*, about 500 peaks, but 2000 to 3000 would not be sufficient if the attempt was made to represent *everything* which is to be seen under good circumstances, and by long-continued observation. It would require a scale three times larger than that of our chart, a giant telescope, and special observations continued over a series of years to complete a drawing of this region of the Moon, which should be equal to the best maps of mountainous regions on the earth." These words of MAEDLER'S, which were printed in 1837, have a prophetic sound, though they were written in ignorance of the photographic methods which DAGUERRE was to introduce two years later, in 1839. The giant telescope, which was longed for, is that of the Lick Observatory. The representation of the Moon, on the more than 3-fold scale of 10 feet to the Moon's diameter, has already been begun by me, using the splendid focal negatives of Mount Hamilton as a basis, after a series of experiments which have enabled me, since April 19, 1893, to enlarge the original negatives more than 20-fold, by photographic processes only, with a sharpness of definition which leaves nothing to be desired.

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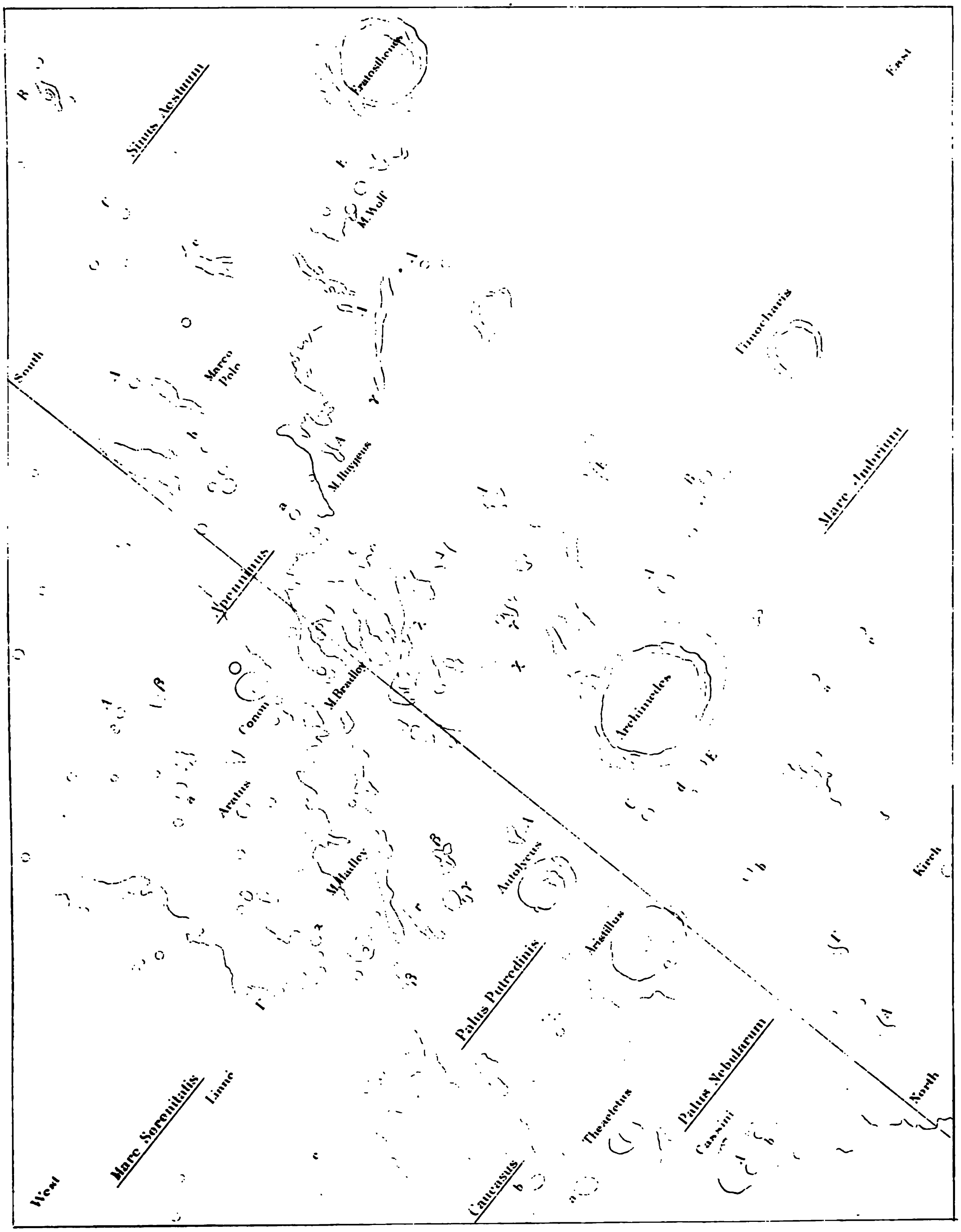
* Translated by EDWARD S. HOLDEN.

The photographic plate which has been employed in making the heliogravure (H) was enlarged about 7-fold, to the scale of MAEDLER'S map, as I have said. I possess a fine positive copy of it (D) on glass by the kindness of the Lick Observatory. D does not reproduce with sufficient sharpness (definition) the grain of the original negative-plate, and in so far does not do entire justice to the finest detail on the lunar surface. It is, in spite of this, a splendid, artistic, and extremely effective picture. The heliogravure (H) is naturally less satisfactory in these respects, though it must be acknowledged to be a marked success; and the *dia-positive* itself (D) is not so satisfactory as the original negative. These conditions must be borne in mind in reading the following discussion of the main features of plate H. It should be stated that I also have in Prague two original negatives of the same night, taken at $8^h\ 16^m\ 26^s.5$ (N_1), and $8^h\ 28^m\ 22^s$ (N_2), so that I am in a situation to test the reality of special features exhibited on H. It should be recollected, furthermore, that negatives, no matter how closely they follow each other, have their own individualities, and that slightly different circumstances in the exposure *always* produce slight differences in the visibility of the very finest details. Such differences can always be interpreted by sufficiently skilled and patient observation, and they can, under some circumstances, be turned to account in explaining the nature of the objects depicted.

To avoid misinterpretation, I wish to emphasize the fact that it is only in the finest details that such differences as I have mentioned are to be found in two negatives taken sufficiently near together. They are chiefly due to differences in


East
Eratosthenes
Sinus Aestuum
M.Wolf
Timocharis
Marco Polo
South
M.Huygens
Mare Imbrium
Apenninus
M.Bradley
Archimedes
Conon
Aratus
M.Hadley
Autolycus
Aristillus
Palus Putredinis
Kirch
Palus Nebularum
North
Linné
Mare Serenitatis
Theaetetus
Cassini
Caucasus
West

the length of exposure of the originals (the exposure-times are purposely varied at the Lick Observatory), but they also depend upon differences in the sensitive films of different plates, particularly in the fineness and in the homogeneity of the grain, on differences in development, and on momentary variations in the steadiness of the atmosphere.

In what follows I shall compare the heliogravure (H) with MAEDLER'S *Mappa Selenographica.* To facilitate this comparison I have prepared the sketch or index-map, by taking all the craters or crater-like objects (denoted either by their round shadows, or by the mark of an illuminated wall) which were to be found on the photograph, and by writing near them their symbols used by MAEDLER. The zero-meridian is also marked (it passes from the east wall of *Aristillus* to the eastward of *Autolycus*), together with the directions N, E, S, W. It is at once seen that H gives not only all the craters laid down by MAEDLER, but also very many more. Among these objects not given by MAEDLER may be mentioned the following. All of them are on the map of SCHMIDT:

1. On the western border of *Sinus Aestuum* lies the easily-seen crater C. East of C, a small definite crater is to be found, at a distance equal to a diameter of *Eratosthenes.* This is not in MAEDLER, although SCHMIDT gives it.

2. To the north of the mountain *Wolf*, in the eastern *Apennines*, H shows three craters. The middle one is not given by MAEDLER.

3. In the southeastern depression of the *Apennine* highland the craters *c* and A are to be found, making a triangle with the crater C, obtuse-angled at *c*, just mentioned. Not far from the middle of the line *c* A, and south of *Marco Polo*, a well-marked crater is shown in H, which is not to be seen in MAEDLER.

4. MAEDLER does not give the small crater which lies in the line A C, not far from C. It is not entirely clear in H, but it is readily seen in D.

5. On the north edge of the central *Apennine* chain, *Cape Huyghens*, A, is to be seen. Southeastward from this, and near to it, on the crest, there is a crater which SCHMIDT gives, but which MAEDLER does not.

6. West from the depression *Marco Polo*, in the highlands, is the crater *b*. Near it, and northwestward, H shows three crater formations near each other, which MAEDLER does not lay down.

7. North of the west end of the broad crater-rill λ, in the foothills of the *Apennines*, SCHMIDT draws an elongated double crater. This is single on H, but is double on D. MAEDLER does not represent it in either form.

8. Northeast of *Aratus*, H shows, outside of the promontory of the western *Apennine* chain, a definite crater, at a distance of one diameter of *Archimedes*. This is not given by MAEDLER.

9. On the western external border of *Archimedes* is a small, round, dark spot,

which has a crateriform appearance. I have given a special note to this (No. 20) in the discussion of my 10-fold enlarged drawing of *Archimedes* from the Mount Hamilton negative of August 15, 1888, to be found elsewhere in this book (*q. v.*). This spot is not in MAEDLER.

10. The height γ lies southwest of *Autolycus*. SCHMIDT draws a small crater on the northern declivity of γ, which is shown in D, but not by MAEDLER.

11. Outside of the western crest of *Autolycus*, SCHMIDT has a crater which is visible in H, much better shown in D, and very plain in N_1 and N_2. MAEDLER does not give it.

12. West of *Aristillus*, at a distance of one diameter of this ring-plain, in *Palus Putredinis*, H shows a definite crater, which is not in MAEDLER. South of this and in its immediate neighborhood D exhibits four small craters (marked by points on the index-map), whose reality is only to be determined by a reference to the original negative.* SCHMIDT gives several low hills here.

13. On the northern declivity of *Cassini*, MAEDLER shows but one crater. According to SCHMIDT there are two such objects. The western one appears (according to H and D) to be extremely shallow.

I may add the following remarks: The broad λ rill, which stretches between *Archimedes* and the *Apennines* (almost parallel to the northern declivity of the mountains), can be admirably seen on H, and its crater character is well signalized. The rill χ, which runs first south and then southwesterly toward λ, from the southern outliers of *Archimedes*, is shown better in D than in H, and distinctly better still in N_1 and N_2. D shows, between the rills λ and χ, two rill-like branches in the form of a St. Andrew's cross (see the index-map). Their true nature can be much better studied on the original negative. West of the height *Autolycus*, γ, SCHMIDT draws a broad rill, which is not shown by MAEDLER or LOHRMANN. The heliogravure (H) shows it very well, but does not permit the long arms, which extend southeasterly, to be easily traced. This rill-system is admirably depicted on N_1. In the western *Apennine* highlands lie the craters *Conon* and *Aratus*, the latter being especially conspicuous. SCHROETER detected a central peak in *Conon*, which was not drawn by LOHRMANN, but which MAEDLER has represented. The Lick photographs fully verify its existence. H shows a large crater joined to *Conon* toward the south, which MAEDLER describes as follows in *Der Mond*, p. 243: "Close to the south of *Conon* there lies a second, rather shallow, crater, and these two are connected by a plateau." It is remarkable that this crater, which is almost as large as *Aratus*, is entirely wanting in SCHMIDT'S chart. On the exterior peak of *Mount Huyghens* there is a small crater, which MAEDLER calls "scarcely visible." The heliogravure represents it, but in N_1 and N_2 it is plainly visible with an interior shadow. The crater *d*, north of *Archimedes*, which only appears as a bright spot on the Mount Hamilton plate of August 15, 1888 (in spite of the fact that the lighting of that negative is similar to the lighting of H—compare No. 23 of the notes to my *Archimedes* drawing in this book—) is here clearly portrayed with an interior shadow. In the interior of *Archimedes* the bright streaks on the floor appear plainly. On the north wall of *Aristillus*, H shows a circular dark spot, whose appearance leads to the inference that it is a crateriform depression. The relief of the ring-mountain *Aristillus* is especially beautifully displayed in the plate, as well as the bright streaks and crests, on all sides, radiating from its center. In Dr. H. J. KLEIN'S *Führer am Sternenhimmel*, p. 318, we read, with respect to the low border-wall of *Cassini:* "The south wall has been shattered by a crater, which is only to be seen in particular illuminations." SCHMIDT does not show this crater. It is, however, easily seen on H, and still better on N_1, which negative also shows the rill which extends from the crater toward the southeast.

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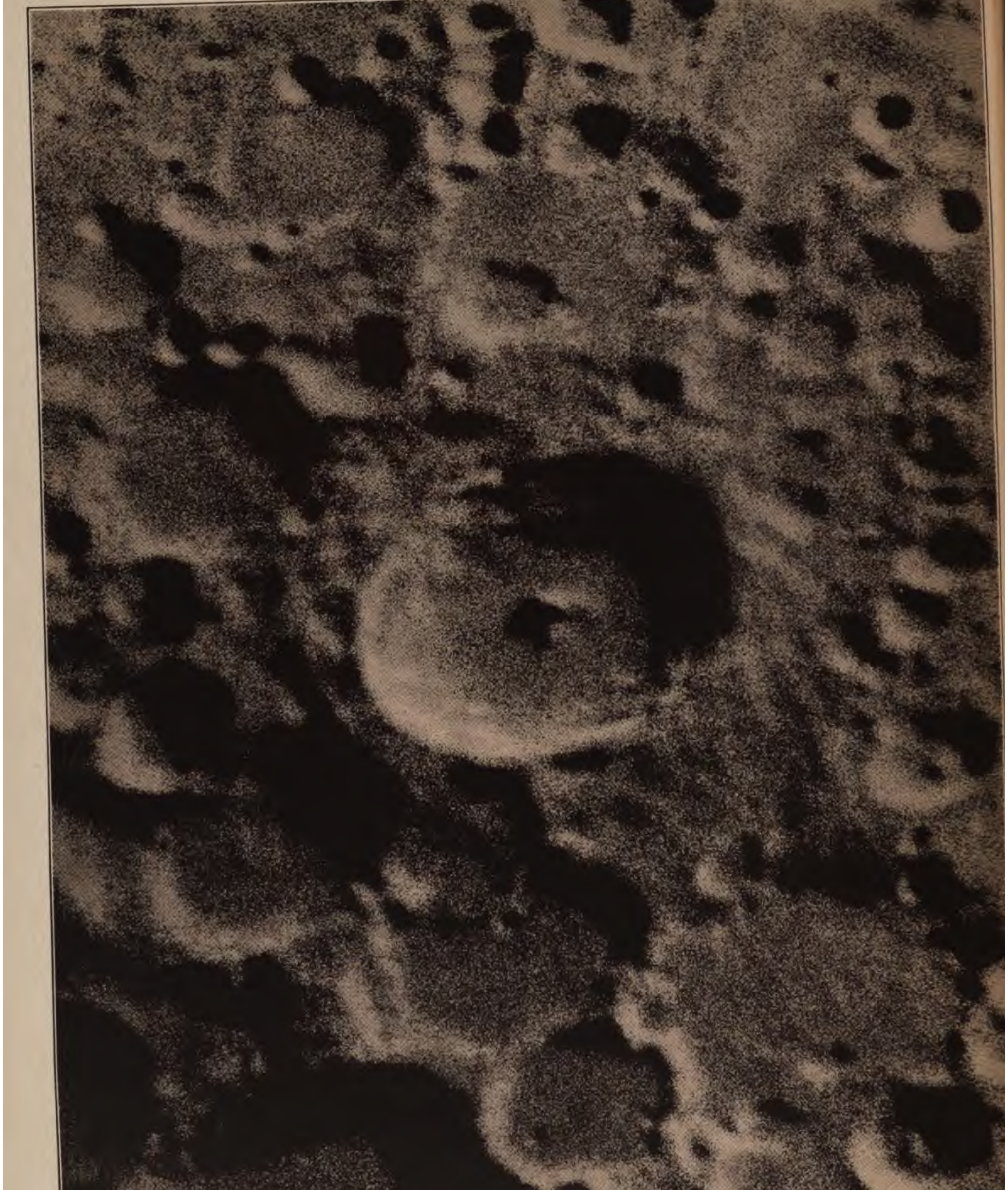
* Note by E. S. H. The original negative shows that the three easternmost dots represent three craters. The westernmost dot probably corresponds to a marking in the crest of a low-lying, rather large crater-ring, and not to a crater-pit. There are a number of crater-pits of the character of the three first named which lie west of *Aristillus*, and which are not given in the index-chart.

The foregoing remarks will suffice to demonstrate that the 7-fold photographic enlargement which we are considering is, even in respect to its minute details, of important value to selenography, and that a further study of the wonderful relief of the landscape shown in the original negatives promises new results.



Photolith. u. Druck v. C. Angerer & Göschl,

TYCHO.

Enlarged 24-fold by Professor L. WEINEK and Dr. R. SPITALER

from the Negative made at the Lick Observatory 1892 November 10 at $15^h\ 52^m\ 41^s$ P. S. T.

PHOTOGRAPHIC ENLARGEMENT OF TYCHO.*

(See the autotype plate facing this page.)

The plate is a reproduction of a direct enlargement made by Dr. SPITALER and myself from an original negative of the Lick Observatory, taken 1892, November 10, at $15^h\ 52^m\ 41^s$, P. S. T., and corresponds to a diameter of the Moon of 10 feet (1 *mm.*, being about 1.06 *kilometers*, $= 0''.57$). The terminator lies on the west wall of *Albategnius*, so that the altitude of the setting Sun for the center of *Tycho* is about 18°. The exposure-time chosen at the Lick Observatory for the original negative was such as to make those parts of the Moon's disk for which the Sun's altitude was some 8°–10°, appear in the negative very much as they appear to the eye in the telescope. Hence the bright wall of *Tycho* is necessarily over-exposed, and shows, therefore, but little detail. In spite of this, the relief of the whole landscape is extremely fine, and the plate affords a comprehensive view of this splendid region such as no artist can ever produce. At the same time the image has one seriously disturbing element, which is due to the enlarged grain of the emulsion film of the original negative. This grain produces a corresponding granular appearance in the plate. If the enlargement had been somewhat less, the general effect of the plate would have been improved. But had the enlargement been less, it would still have been necessary to examine the resulting plate with a hand-magnifier in order to see the finer detail, and it was my object to do away with this necessity. On the 24-fold enlargement the finer detail can be seen with the unassisted eye, so soon as one has learned to inspect the image without being disturbed by the grain. The effect of the grain can be counteracted by examining the picture at a greater distance than that of distinct vision, or by covering it with a paper more or less transparent, as required, so as to obtain its generalized aspect.

This plate of *Tycho* has been exceedingly well reproduced by the comparatively cheap method of *phototypie* (using the well-known fine net-work of squares and subsequent transference to stone) by the k. u. k. Hof-Photographischen Kunst-Anstalt, C. ANGERER & GOESCHL, of Vienna. The plate is naturally somewhat inferior to the 24-fold enlarged glass *dia-positive*, particularly because the half-dark tones within the deep shadows, or just at their borders, have been made unduly dark, and are thus more or less missing. The same thing occurs to some degree, however, even in the best silver prints on Aristo paper. For this reason the shadows in the plate are in general a little too much extended toward the west; especially so in *Pictet* and in *Pictet*, *a*, where half-dark elevations in the interior, which are easily seen in the *dia-positive* (with dimensions of 3 to 5 *mm.*), have been overlaid with black shadows. A few outlines of crater-walls have been entirely lost for the same reason, as on the inner southeast wall of *Tycho*, on the southeast wall of *Sasserides*, and on the south wall of *Orontius*. In other respects the reproduction is completely truthful, with the exception that the forms of the truly circular grains of the enlarged *dia-positive* (whose diameters are from 0.07 to 0.10 *mm.*) are somewhat modified on the plate by the action of the net-work of small squares necessarily employed in the *phototypie* process.

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* Translated by EDWARD S. HOLDEN.

A picture, in relief, of the same region on the Moon, near sunset, has been given by SCHMIDT in his book *Der Mond* (Leipzig, 1856). If we compare SCHMIDT'S drawing (which is about three and one-half times smaller than the plate) with the enlarged photograph, we see at once that the drawing appears highly schematic and incomplete, and that even the outlines leave much to be desired. Another extremely sharp plastic representation of *Tycho* (after sunrise) is to be found in NASMYTH and CARPENTER'S work on the Moon in their plate XV. If this plate is compared with the photograph, we see at once that it presents very many inaccuracies—often arbitrary in their nature—as indeed is to be expected, since NASMYTH and CARPENTER'S plates were copied from a model globe of the Moon, made by them in relief from their long-continued series of Moon drawings obtained at the telescope. I have myself twice drawn *Tycho* with the 6-inch telescope of the Prague Observatory. The first drawing was on 1884, April 4, with the shadows thrown to the east (see *Prager Astr. Beob.*, v. 1884), and the second was on 1885, January 8, with the shadows thrown westwards (see *Prager Astr. Beob.*, v. 1885–1887). Although these drawings are on a comparatively small scale, their agreement with the photograph may, in general, be considered as satisfactory.

Among the maps of *Tycho* and vicinity, that of SCHMIDT, in Section XXIII of his atlas, is the most complete, and for this reason a comparison will be made between SCHMIDT'S chart and the photograph. A second original Mount Hamilton negative of the same evening (1892, November 10, $14^h\ 54^m\ 31^s$, P. S. T.) is in the possession of the Prague Observatory, and has been used to verify the reality of the finer details which appear on the photographs, but which are not to be found on SCHMIDT'S atlas. The latter negative I shall call II, the former I. A rigid comparison of I and II was very conveniently made, as follows: A 24-fold enlarged *dia-positive* was made from each negative, taking pains that the two enlargements should be of like sharpness and intensity. Each of these *dia-positives* showed objects in very nearly the same absolute dimensions. Each was examined by transmitted light, and illuminated by diffused daylight. If the question was, for example, to identify rills which passed through or near a certain crater, two independent sketches of this crater and its vicinity were made, one from each *dia-positive*. The lines on the first sketch were given in red; on the second, in black ink. When the two sketches were superposed, identical features should cover each other. Even in the case where the scale of the two *dia-positives* is not precisely alike, this method of comparison can be readily employed by taking account of the scale difference referred to. It is to be remarked that, in general, the crater-forms were better defined and more easily seen on I than on II, though the latter plate showed a few rills better than the other. To the south of *Tycho*, at a distance slightly greater than the meridional diameter of that crater, lies the ring-plain *Street*, *d*, which has a larger crater on its southeast wall. This is shown at the left hand upper margin of the plate. If the centers of *Street*, *d*, and *Tycho* are joined, the joining line represents the direction of a meridian. The direction from the center of *Tycho* to the right hand upper corner of the plate is, accordingly, east; to the right hand lower corner, north; and to the left hand lower corner, west.

1. SCHMIDT has drawn, in the interior of *Tycho*, a central mountain which is extended east and west, and north of the west end of this mountain he has depicted an elevation. Closely adjacent to this elevation, and to the south, SCHMIDT has mapped a small crater. The elevation in question is easily seen on I and II. The small crater cannot be made out on the phototype, because the shadow of the central mountain is broadened at this place and is too intense; it can, however, be seen on II at the edge of the shadow, and it is with difficulty made out on I. According to II its diameter is about 2 *kilometers*, which agrees very well with its dimensions in SCHMIDT'S chart. On I, nearly in the meridian line through the center of *Tycho*, and on the southern summit of the great central mountain, a rounded formation is to be seen, which is a crater of 1.4 *km.* in diameter. This is also shown on II. On the northern border of the interior of *Tycho*, SCHMIDT has laid down a very small crater, which was first observed by him on August 27, 1842. This crater lies in the line joining *Sasserides*, F, and the western edge of the central mountain. This small crater is well seen on I, less plainly on II. At the northeast foot of the central mountain there appears (on I and II) to be a rill-formation extending toward the northeast wall of *Tycho*. Southeast of this rill-formation there are (according to I) several small craters. Westerly from the central mountain there appears to be a rill (on I and II), which traverses the western parts of the interior of *Tycho* in a northeasterly direction. The terraced

formation of the bright western interior wall of *Tycho* is lost, in a great measure, in the plate. But both *dia-positives* seem to show, so far as one can tell, a group of small craters on the southwest wall. On the northern outer wall of *Tycho*, I shows a curved fissure, or rill-line, which passes through two plainly marked craters, and which has somewhat the shape of an entended Latin W. This is especially well seen on II, in which plate the westernmost one of the two small craters is particularly well defined.

2. West of *Tycho* lies the ring-plain *Pictet* (which SCHMIDT calls I *b*). The ring-plain *Pictet*, *a*, joins this on the south. SCHMIDT has drawn the latter formation very much too small, and he has placed it too far to the west of *Tycho*. On the other hand, SCHMIDT'S map, Section XXIII, gives the distance between *Pictet*, *a*, and *Street* (which SCHMIDT calls I *a*) too large. This interval is filled on SCHMIDT'S map by two ring-plains, the northernmost of which encroaches on the most southerly. The photograph seems to show in this place only one ring-plain (whose diameter is about 0.7 of that of *Pictet*, *a*), which is, however, divided into two parts by a low elevation. NASMYTH and CARPENTER represent only one ring-plain here, while MAEDLER has nothing in this place.

3. East of *Street*, *d*, lies a large ring-plain, which SCHMIDT calls M, and LOHRMANN, 159. According to SCHMIDT, M has a large crater on its northwestern outer wall, and this latter crater has, again, a small crater attached to it on the east. The last described object is shown by the photograph to be imbedded in the wall itself, and can scarcely be smaller than its neighbor to the west. Adjacent to the northern outer wall of M, SCHMIDT has a considerably large and apparently deep ring-plain. Both photographs agree in showing that this ring-plain is shallow. On the northwest outer wall of this last-named object, I shows a well-marked crater-rill, in which four craters are to be seen, of which two are especially plain, each having a diameter of 2 *km*. This crater-rill is less plainly shown on II.

4. Somewhat further to the north lies the small ring-plain *Tycho*, *d*, inclosed in a large ring-plain (east of *Tycho*). I shows a plainly marked rill-formation, which passes through the middle of *d*; on its western inner margin is another formation of the same kind, and both of these seem to extend as far as the southeast wall of *Tycho*. The plate II confirms these conclusions, though the easternmost of the two rills is seen with difficulty, while on the other hand, the westernmost is very plainly shown, and can be clearly identified. On the plate I still another well-marked rill is to be found in these regions; it runs between the easternmost of the two rills just described and the crater *Tycho*, B, in a northwesterly direction, up to the outer wall of *Tycho*, and is also shown on plate II. According to II there is a nodal point in the latter rill south of *Tycho*, B, and from this point there extends, to all sides, a family of radiating rills. The nodal point is shown by I to be

undoubtedly a crater. The small crater which SCHMIDT lays down on the northwest wall of *Tycho*, B, is well shown on I. Both I and II also show a crater of similar dimensions on the border of the north wall of *Tycho*, B.

5. Plate I displays an obvious rill-formation, which extends in a north and south direction from *Tycho*, B, to *Tycho*, *f* (the middlemost of the three craters which lie close together northeast of *Tycho*). This rill appears to be connected with the small crater situated on the south wall of *f*, and to have there the characteristics of a crater-rill. Close to it and to the east, yet other small craters are visible. The plate II exhibits the northern half of the above described rill pretty well. From the small crater just mentioned, on the south wall of *f*, plate II shows a very obvious rill, which extends toward the northeast wall of *Tycho*, before which wall it divides into two branches. The principal branch is easily seen on I. Moreover, plate I shows a rill-formation between the outer southwest wall of *Tycho* and *Pictet*, *a*, which extends in the direction of the meridian, and whose position is completely confirmed by plate II.

6. Another very obvious rill-formation extends (according to both I and II) from the northwest outer wall of *Tycho*, through the well-marked crater lying northeast of *Pictet*, C, up to the south wall of the ring-plain *Sasserides*, *a*. Plate II shows that the unnamed crater just described contains a small central crater of 1.2 *km.* in diameter, which is a center from which a system of rills radiates on all sides. Northwest of this crater SCHMIDT depicts two smaller craters in the interior of the ring-plain there situated, and these two small craters are well shown on I by their limiting outlines. Several other similar craters seem to exist at this place also.

7. The central conical mountain of *Sasserides*, A, is plainly shown on I and II. I shows it to have a crater on its western slopes, and from this crater two or three rills radiate. The photograph also shows a high central mountain in *Sasserides*, C, although SCHMIDT does not lay down any such peak, but rather a semi-circular elevation, with its open side toward the west. In the neighborhood of *Sasserides*, F, and to the east, I shows a large ring-shaped formation, which is also indicated on II. Both *dia-positives* show several small craters within this formation.

8. *Sasserides* contains several rills according to I. One of them extends from the southern margin of the eastern large walled crater, and runs toward the west, dividing as it goes. The others radiate from a point which lies on the inner wall of *Sasserides*, northeast of *Sasserides*, F, and only a short distance from it. *Dia-positive* II shows a clearly defined small crater here, and plate II confirms both systems of rills. On the southwestern inner wall of *Sasserides*, SCHMIDT has a great number of small craters, which are well seen on I.

9. In *Sasserides*, *a*, there is easily seen (on I) a large, leaf-shaped rill-formation

whose apex is directed to the northwest. The area included within it seems to be convex. The same characteristics are shown, although less distinctly, on II.

10. In the northern interior of *Pictet* is a well-marked rill extending north and south, which seems to pass through several small craters. This rill is shown on both I and II. A similar rill lies east of it, at a small distance, which is plainly visible on I and II, although in the phototype it falls within the limits of the dark shadow. I and II show a rill extending along the southeast crests of *Orontius*, and this is especially well seen on II.

In what precedes I have given only a few comparisons of the plates I and II. A more thorough discussion would require a completer nomenclature for the various objects than is now available. Yet the very summary account here presented will abundantly show the great importance of photographic enlargements, like that of *Tycho*, in spite of the confusion of the finer details which results from the grain of the sensitive film.

L. WEINEK.

Prague, March 28, 1894.

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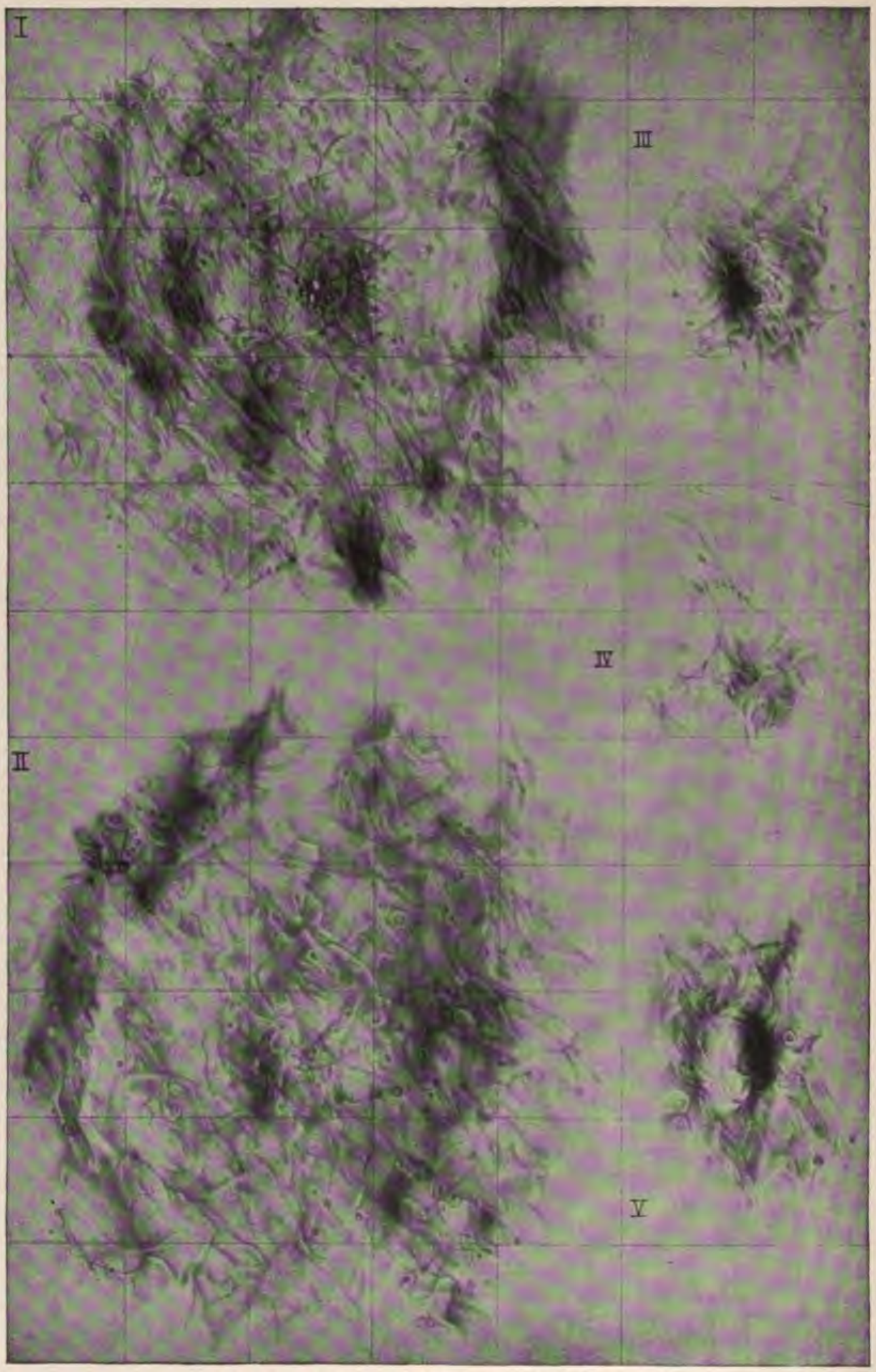

Capella, (I, II); Taruntius, C, (III, IV, V).

CAPELLA AND TARUNTIUS, C.*

(See the phototype facing this page.)

[Professor L. Weinek, Director of the Imperial Observatory of Prague, has submitted to the Imperial Academy of Sciences of Vienna, as a continuation of his recent lunar studies, drawings of the ring-plain *Capella* and of the crater *Taruntius*, C, enlarged forty times from photographs taken at the Lick Observatory. His explanatory remarks are as follows:]

Drawings I and II represent the interior of the ring-plain *Capella;* drawings III, IV, and V show the small crater on the north wall of *Taruntius*, which Maedler calls C.

These five drawings are enlarged exactly forty times from the following photographs taken at the Lick Observatory:

I. From Lick Observatory negative, 1890, November 17.
$6^h\ 8^m\ 35^s$ P. S. T.; Moon's age $= 5^d\ 12^h.5$.
II. From Lick Observatory negative, 1890, August 31.
$14^h\ 27^m$ P. S. T.; Moon's age $= 16^d\ 18^h$.
III. From Lick Observatory negative, 1890, November 16.
$5^h\ 53^m$ P. S. T.; Moon's age $= 4^d\ 12^h$.
IV. From Lick Observatory negative, 1890, July 20.
$7^h\ 53^m$ P. S. T.; Moon's age $= 4^d\ 3^h$.
V. From Lick Observatory negative, 1890, August 31.
$14^h\ 27^m$ P. S. T.; Moon's age $= 16^d\ 18^h$.

Both pictures of *Capella*, in which the shadows are cast in opposite directions, have exactly the same position in reference to the Moon's meridian, so that the vertical lines of the reticle represent the direction of the meridian for this locality of the Moon.

The exact orientation was found by turning plates I and II in such a manner that the east crest of *Capella* and the east rim of crater D, northeast of *Capella*

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*Translated by F. R. Ziel, from the *Sitzungsbericht* of the Imperial Academy of Sciences of Vienna, July 6, 1893, and reprinted in the *Publications of the Astronomical Society of the Pacific*, volume V (1893), page 158.

(which objects Maedler places in almost the same meridian), coincided with one of the vertical lines of the glass reticle, which was divided into spaces of one half *millimeter*, and which was used in making the enlargement. Likewise the three drawings of the crater *Taruntius*, C, were located exactly similarly in reference to the meridian of the place, which is also shown by the vertical lines of the picture.

The Central Peak in Capella.

Mr. C. M. Gaudibert, of Vaison (Vaucluse), in writing to me on April 27, 1893, called my attention to a small crater which he discovered on May 24, 1890, on the summit of the central peak in *Capella*, which he describes in the *Revue mensuelle d'Astronomie populaire*, Février, 1892, p. 64, as being excessively small at the time of first observation; but at present he is able to see it without difficulty, so that Mr. Gaudibert is led to the belief that this summit-crater may have lately attained a larger diameter.

I was much interested by Mr. Gaudibert's information, and proceeded to search for this crater on Lick Observatory plates of the year 1890, for the purpose of ascertaining whether the photographic representation was inferior or superior to the optical observation.

Mr. Gaudibert states that during the whole of the year 1890, and until September 20, 1891, although he searched for this crater whenever opportunity offered, he was unable to verify his first observation; which is no doubt a proof that the optical observation of the crater was extremely difficult during the year 1890.

I had no trouble in finding this summit-crater on two plates (I and II) of 1890, with shadows falling in opposite directions, and was, moreover, led to the discovery of several formations of rills and some much smaller craters in the vicinity; the enlargement of 40 diameters shows an exceedingly small crater (having a diameter of only 0.8 *mm.* = 0.50 *km.*, viz.: 0.28 *mm.*, on Schmidt's map) to the east, which is identified on both drawings I and II, as well by its position as by its size.

I may state that the round outline of this minute crater on plate II is of the same order of size as the lines of the faintest rills discovered photographically. I have found, after making numerous measurements, that the grain of the photographic plate, under an enlargement of 40 diameters, has a size of only 0.10 to 0.17 *millimeters;* this agrees well with Professor Eder's measurements in *Die photographische Camera und die Momentphotographie*, 1892, page 698, which place the size of the grain of quick dry-plates at 0.003 to 0.004 *millimeters;* so that the grain is about five to eight times smaller than the diameter of the above-mentioned crater.

Plate I shows the summit-crater very clearly, and was taken at about the same age of the Moon as that on which the optical discovery was made, viz., May 24, 1890, the Sun being about 18° above the morning horizon; whereas for plate II the altitude of the Sun was about 28° above the evening horizon. The greater altitude of 10° in the latter case is probably the reason why the crater is not so plainly shown on plate II, where it is hardly more than outlined. The visibility of a crater is naturally also governed by its inner slope toward the west or east, as the case may be, which is not known beforehand. In general, the conditions exhibited on plate I appear to be more favorable for *Capella* than those of plate II.

The small crater discovered by GAUDIBERT on March 15, 1891, on the western slope of the central peak, is well visible on plates I and II; on the former with a distinct round outline without much shadow, on the latter with a shadow.

The first-mentioned manner of photographic representation of small craters is very interesting, and is quite frequently met with on the photographic plate, but as a rule becomes apparent only by strong magnification, and in many cases furnishes the proof of the existence of an optically observed crater, which, owing to the not quite favorable exposure-conditions of the plate, had apparently been lost on the latter.

Southeast from the summit, at the base of the peak, there are three larger craters, of which the two outer ones can be identified on plates I and II without difficulty. The middle one, however, is barely visible on plate I, although quite plain on plate II.

Among the many small craters, including some as small as one-sixth of the diameter of the summit-crater on both pictures, which appear principally as perfectly circular outlines, and which can in some cases be traced on plates I and II (on plate I the Moon's distance from the earth is a little greater than on plate II), we observe on plate II a circle of four distinct craters on the southwest wall of *Capella;* of these the most easterly one is also shown on plate I. A very delicate rill-formation, extending from the summit-crater in a southwesterly direction, and which is finally divided in the shape of a fork, can be identified with certainty on both plates.

Plates I and II show a great number of chains of delicate undulations, low elevations, and faint rills, the general direction of which is perpendicular to the Sun. Among these we may mention several chains on the peak itself, which converge toward the summit-crater, and therefore probably originate in the latter.

Finally, I may mention that the time employed in the production of drawing I was 20½ hours, and of drawing II, 25 hours. Considering this relatively short time of drawing it was only possible, in both cases, to make an exact drawing of the central peak, while the rest has merely been sketched, although it is correct in reference to position and shows all the important detail.

TARUNTIUS, C.

Plates III and IV, in which the shadows are cast in the same direction, and plate V, in which they fall in the opposite direction, show that there is another smaller crater at the bottom of this crater, which, on plate V, gives the impression of being slightly convex, and has a small crater-opening in its center. The size and shape of this inner crater agrees well in all three cases.

The diameter along the meridian is equal to 3.5 *millimeters*, or 2.23 *kilometers*,[*] or 0.30 geographical miles on the enlargement of 40 diameters, whereas the diameter of the inner crater-opening is 0.25 *kilometers*.[†]

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[*] $1\frac{4}{10}$ English miles.

[†] $\frac{15}{100}$ English mile.

NEW FEATURES ON THE MOON DISCOVERED IN EXAMINING THE NEGATIVES OF THE LICK OBSERVATORY.*

By Professor Weinek.

In the course of enlarging the focal Moon-negatives made at the Lick Observatory, by drawings and by photography, and also in the process of comparing two or more Mount Hamilton plates together, I have found a considerable number of rill-like and crater-like objects which were not laid down in any of the existing lunar charts. When such an object is detected, it is at once necessary to determine whether it is a veritable feature of the Moon, or whether it is only an accidental flaw in the structure of the film of the sensitive plate. This determination was readily and safely effected whenever the object could be found, in its true position and its true dimensions, on two or more plates; that is, whenever its appearance was such that it required no forced artistic interpretation to find the object. In cases where this could not be done, the determination of its reality was naturally much more difficult, because rill-like lines and crateriform objects are present in the grained films of the dry-plates used at the Lick Observatory, even in those portions which have not been affected by light. Under such circumstances, the processes of interpretation which have been derived from the examination of *known* rills and craters must be the basis of one's final conclusion. In spite of this it must always be emphasized that a particular object was found on only a single plate, and hence that its reality has not been conclusively established. A later photograph, or a visual verification, is then required to supply the necessary evidence.

At the commencement of my detailed studies of the Mount Hamilton negatives, it was already known to me that they showed a certain disturbing structure of the granular film exterior to the Moon's disk. This structure was sometimes evidenced by coarse diffused grains; sometimes by particular patterns of large extent; or, again, by small dark spots. While it could not be taken for granted that the exposed portions of the plate would display the same appearances as those portions unexposed to light, the matter could nevertheless be tested by comparing those parts of the film on the borders of the exposed and unexposed portions—as, for example, at the bright limb of the Moon. Here we do, in fact, see the lines of single grains of the unexposed regions extending over into the exposed areas, although they there become very faint and ill-defined. This fact evidently makes it more difficult to determine the reality of a rill-like line discovered in the image of the Moon; but it does not render it impossible to a practiced observer. When the rill-like object is really formed by the grain of the film, it appears as a small vacancy *between* the separate grains of the film, whereas if the object is veritably a rill in the Moon, it is seen to lie *upon* the separate grains of the sensitive film. The difference is easily to be seen under high magnifying power, or by a considerable direct photographic enlargement in the camera. In order to test the reality of such objects still further, it is desirable to illuminate the negative (not a positive) in all possible ways, both from the front and from the reverse side, so that the shadows of the separate particles of the film may be thrown in very many different directions. By varying the shadows it is possible to see if the rill itself is constant; that is, we become, in a sense, independent of the grain of the plate.

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* Translated by Edward S. Holden. It was necessary to send the MS. of this section to the printer before the translation had been seen by Professor Weinek. It has been thoroughly revised, however, by Professor Schaeberle.

In the examination of veritable rills on the Moon the following important and often decisive characteristics are to be found: (1st) When seen their direction is usually perpendicular to the direction of the Sun's rays; (2d) They often present bright walls on the side farthest from the Sun; (3d) They are connected with small craters, through which they run or from which they radiate; (4th) They correspond completely with the topography of their particular region of the Moon, and with the photographic representation of this region. If no bright walls to a supposed rill are visible in a given negative, it remains doubtful whether one has to do with a veritable rill or with the shadow of a low elevation (just as if the observation had been made visually at the telescope). In any event, it can do no harm to have called attention to rill-like objects on the Moon, provided that all doubtful cases are specifically mentioned, and that the question of their reality is left open.

Tests of the sharpness of definition of the photographic plate are of the first importance in all questions of new discoveries, just as they are for enlargements, whether by drawing or in the camera, and such tests must be made at the very beginning of the work. This is done by searching for known objects of small dimensions on the plate (having regard, however, to the nature of the background on which such objects are projected, as well as to the suitability of the exposure-time of the plate for showing this particular class of objects), and also by examining the image of the full limb of the Moon, *both* in R. A. and in Decl. Since the proper motion of the Moon during the exposure-times of 2^s–4^s is not compensated, the shifting of the image on the plate during this interval may interfere with the definition. In all cases only those plates having the greatest possible sharpness of definition should be employed.

In what follows I have brought together some discoveries made upon the Lick plates. In the descriptions I have used the word "*rill*" in its most general sense, so as to include shallow depressions on the Moon, whether straight or sinuous. Usually these formations are of considerable length, and of relatively small width. In each description I have named first the Mount Hamilton plate, upon which the discovery was made, with the time of the exposure, expressed in Pacific standard time (P. S. T.) (Greenwich mean time *minus* 8^h), and the age of the Moon, *Age*. Then follows in parenthesis the figures (1 +) or (1), meaning that the object in question has been seen on more than one plate, or on only one. In case it has been seen on only one plate, my judgment in all cases here given is that the object is a real one. Then follows a brief description of the region in which the object referred to lies, and a short description of the object itself—employing generally the nomenclature of SCHMIDT. In most cases I have prepared special drawings of the new objects and their surroundings. It has not been practicable to reproduce these drawings in this volume, but they will be published in due time in the *Annals* of the Prague Observatory. Then follow notes of visual verifications of the discovery, when such have been made, and finally the date on which the new formation was first detected.

L. O. plate, 1888, August 27, ... ? P. S. T.* *Age* = 20 days; (1 +).
In *Thebit*.

The inner floor of *Thebit* is traversed, in its western half, by a long rill-valley. On the *dia-positive* described above, it shows as plainly as the well-known rill to the west of *Triesnecker*. This rill-valley begins at the inner south wall. In the first third of its course its direction is northeasterly; in the second third, northwesterly; and it then takes a meridional direction, and appears to end near the elevation ε.

Its distance from the west wall of the crater *Thebit*, A, is about one diameter of this crater. West of the southern part of this rill-valley there is a short crater-rill lying nearly in the meridian. On the north border of the interior of *Thebit* there is a small crater, which is erroneously placed by MAEDLER and by NEISON on the outer wall at this place. The photograph shows a fine rill which runs from this crater toward the south and southwest. A more detailed description is given in *Prager Astr. Beob.*, v. 1888–1891, pp. 76–78.

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* The negatives made by Professor BURNHAM in 1888 have no indication of the hour and minute.

Visual Verification. The principal course of the rill-valley was traced by me on March 31, May 28, May 29, 1891, and on February 18, 1892; by C. M. GAUDIBERT, in Vaison, on August 4, September 2, September 3, 1893 (see *English Mechanic*, December 1, 1893, p. 328); and by A. S. WILLIAMS, in West Brighton, on September 2, 1893 (see *The Observatory*, December, 1893, p. 411).

The latter observer also considered the object as a rill-like valley, and observed yet another branch rill, which runs from the north end of the valley toward the southeast. This branch is difficult to see on the *dia-positive* of August 27, 1888, but very easy on other negatives. GAUDIBERT also recognized on August 4, 1893, the short crater-rill, above described, by its course. A small double-crater, lying in the eastern interior of *Thebit* (to the west of the western crests of *Thebit*, A, at a distance of about one third of the diameter of A), was discovered by V. NIELSEN, in Copenhagen, on November 12, 1891; and it has been found by him on an enlargement made at Prague from the *dia-positive* above named. (See *The Observatory*, October, 1893, p. 352.)

Discovered the last of March, 1891.

L. O. plate, 1888, August 15, ... P. S. T. *Age* = 8 days; (1 +).
Near *Chladni*.

Southeast from *Triesnecker*, A (called *Chladni* by LOHRMANN), at a distance of about three diameters of A, this plate shows a plain, round crater, filled with shadow, whose diameter is at least 4.8 *km*. This is also found on other plates, usually in contour only, and it appears to need a special azimuth of the Sun to be well seen. Southwesterly, a low conical mountain is attached to this crater in the direction toward the crater B. The base of the mountain measures about 16 *km*., and its apex contains a small crater of 1 *km*. in diameter, from which rills stream in various directions. A full description is given in *Prager Astr. Beob*., v. 1888–1891, pp. 78–81.

Optical Verification. The above-described objects were optically verified by Professor HOLDEN on June 15 and October 10, 1891, with the 36-inch refractor of the Lick Observatory. On the date first named the conical mountain, with its summit crater, was seen, as well as a small crater on the southeastern border of the mountain; and on the second date the larger crater above mentioned. According to the observer the latter is not fully surrounded by a crater-wall, and its interior is only filled with shadow when the Sun's rays strike it from the northwest. When the Sun is farther south the crater shows no interior shadow. Several rills appear to debouch within the crater.

Discovered 1891, May 22.

L. O. plate, 1890, August 31, $14^h\ 27^m$, P. S. T. *Age* = 16 days 18 hours; (1 +).
In *Cleomedes*.

In the southwest interior of *Cleomedes* there is a rill-system, whose plainest rill passes nearly half way between the craters B and *n*. In the middle of its course this rill runs nearly north and south; in its southern part, southwesterly; and in its northern part, northwesterly. It stretches from the inner south border of *Cleomedes* to its southwest border. This rill is crossed by a second one, which runs from the crater *n* toward the northeast. On the northwest wall of *Cleomedes* lie four very small craters, nearly in a meridional direction. They are successively smaller as one goes from north to south, and vary between 1.6 and 0.3 *km.* in diameter. (See *Prager Astr. Beob.*, v. 1888–1891, pp. 81–83.)

Discovered 1891, November 19.

L. O. plate, 1888, August 23, ... P. S. T. *Age* = 16 days; (1 +).
In the northwestern interior of *Mare Crisium*.

Here there is a large crater, marked *s* by SCHMIDT (NEISON calls it *Eimmart*, *c*). Going south from its eastern wall one comes to a long, low hill. From this two plain rills run to the east, converging as they go. The northerly rill is about 2.4 meridional diameters of the crater *s* from the south border of *s*; the southern rill is distant about 3.0 such diameters. Their length measured to their point of meeting is about 1.4 diameters. They are crossed by several fine rills. (See *Prager Astr. Beob.*, v. 1888–1891, p. 83.)

Discovered 1891, November 21.

L. O. plate, 1888, August 23, ... P. S. T. *Age* = 16 days; (1 +).
To the west of *Taruntius*.

A long rill-formation runs from the southwest outer wall of *Taruntius* almost exactly west, and traverses the whole of *Mare Fœcunditatis* to the eastern foot of the mountain region which lies south of *Mare Crisium*. A branch of this rill near the west wall of *Taruntius* has a northwesterly direction. South of the crater *Taruntius*, A, there lies, in the direction of a meridian, at a distance of one diameter of this crater, a short crater-rill; between the latter and A there is a rill-valley lying east and west. There is yet another meridional rill west of A, passing close to this crater. In the southwestern interior of *Taruntius* there is a rill-system with many branches, which is connected with the small crater laid down by SCHMIDT on the southern border of the interior. An arm of this rill-system passes close to the west of the central mountain as far as the northwest wall of *Taruntius*. The central mountain appears to have a very minute crater on its southern crest. (See *Prager Astr. Beob.*, v. 1888–1891, pp. 84–85.)

Discovered 1891, November 22.

L. O. plate, 1890, August 31, $14^h\ 25^m$, P. S. T. *Age* = 16 days 18 hours; (1 +).
To the north of *Picard*.

In the southeastern part of *Mare Crisium* lies the crater *Picard*. From this crater there runs a broad, but not deep, rill-formation toward the north. At a distance somewhat greater than a meridional diameter of *Picard* it divides into two branches; the entire system resembles a Greek λ in shape. Its entire length, counted from the north wall of *Picard*, is two meridional diameters of this crater. West of *Picard*, and pretty near the foot of its outer wall, there is a rill which runs in a meridional direction in almost the same longitude as *Picard*. (See *Prager Astr. Beob.*, v. 1888–1891, p. 85.)

Discovered 1891, December 1.

L. O. plate, 1891, October 12, $7^h\ 29^m\ 9^s$, P. S. T. *Age* = 10 days 2½ hours; (1 +).
In *Longomontanus*.

A rill-like formation of but little depth runs westerly from the central mountain across the entire interior of this wall-plain. It lies nearly in a meridian from the south wall as far as the middle of *Longomontanus;* then it bends sharply and runs northeasterly up to the north wall. Its entire course is marked by bright walls. Its breadth is, on the average, 1 *km*. A second rill begins at a crater of the southwest wall (the crater toward which SCHMIDT'S crater-rill B leads) and runs as far as the southern central-peak, first passing the crater drawn by SCHMIDT in this place. This second rill intersects the southern part of the rill first named nearly perpendicularly from the middle of the southern central-peak. An obvious rill-valley runs in a northwesterly direction past the northern central-mountain. There seems also to be a short rill in the southeastern interior, in which place it cuts obliquely and nearly in a meridional direction the row of four small craters there laid down by SCHMIDT.

Discovered 1892, January 31.

L. O. plate, 1888, August 27, ... P. S. T. *Age* = 20 days; (1).
In the eastern interior of *Walter*.

This plate shows two hollow depressions, filled with shadow, between the crater *e* and the horseshoe-shaped elevation connected with the mountain summit β (NEISON). Let us call the southernmost *a*, the other, *b*. *a* lies half way between *e* and the height β, is very nearly round, has a diameter of 2.8 *km*., and shows a central, very black point, 0.51 *km*. in diameter. *b* lies near to β, is an oval, with the major axis in the direction *e* β, and is somewhat larger than *a*. Near *a*, to the southwest, there are two more small depressions, whose dimensions are each about

1.3 *km.* All four of the depressions just described are connected with fine rills, which lie in a direction normal to the Sun's rays. The most obvious rill in this neighborhood runs, with various flexures, between *a* and *b*, and then northerly from *b* and *β*. In its northern course, it passes several small craters. The Lick plate of 1892, November 10, $14^h\ 54^m\ 31^s$, P. S. T., shows the crater-depression *a* to be connected, by means of a plain rill, with the small crater drawn by SCHMIDT on the east wall of the crater *e;* and from this latter point several rill-formations appear to radiate. The Lick plate of 1891, July 14, $8^h\ 16^m\ 26^s$, P. S. T., exhibits, moreover, an obvious crater, with an interior shadow and a bright wall, nearly half way between the crater A (MAEDLER) and the northernmost crater of the series of craters lying west of *e*. Its diameter is 2.8 *km.* It would lie on SCHMIDT'S map, Section VIII, somewhat to the left and above the figures 18 in the interior of *Walter*. There is a second crater, somewhat smaller, to the southeast; and, finally, a third crater, southeast of the second, at a distance of almost one diameter of A. The diameter of the third crater is 1.6 *km.*, and several rills radiate from it. The existence of the first crater is fully verified by the Lick plate of 1888, August 15, upon which its bright wall and interior shadow are shown.

Discovered 1892, February 6; 1894, May 22.

L. O. plate, 1890, August 31, $14^h\ 27^m$, P. S. T. *Age* = 16 days 18 hours; (1 +). Between *Petavius*, B, and *Santbech*, *b*, in *Mare Fœcunditatis*.

A long rill extends nearly easterly from the east wall of *Petavius*, B (somewhat to the south of its center), to the northwest wall of *Santbech*, *b*. It runs somewhat to the south of an elevation which lies half way between *Petavius*, B, and *Santbech*, *b*. (An obvious crater, which we shall call *m*, lies farther to the south of the elevation referred to.) The rill appears in most of its course only as a bright line (usually well defined), because its direction lies parallel to that of the Sun's rays. A branch rill runs, in the region northwest of *Santbech*, *b*, through the series of craters there situated, and extends farther toward the west, in a line nearly parallel to the first rill. A third rill has the same origin (at the east wall of *Petavius*, B) as the first rill, and runs toward the northeast. A short rill runs to the north from the crater *m*. SCHMIDT has drawn a tong-shaped elevation northeast of *Petavius*, B, and farther to the east two craters, which are only slightly smaller than *m*. The photograph shows a third crater, whose diameter is 1.5 *km.*, southeast of SCHMIDT'S two craters, and near to them.

Discovered 1892, February 11.

L. O. plate, 1888, August 27, ... P. S. T. *Age* = 20 days; (1 +).
In and near the crater *Hell*, B.

A rill runs through the entire eastern half of the crater *Hell*, B, in the direction of the prolongation of the eastern border of an elevation which is connected to this ring-plain on the south. The rill is slightly convex toward the west. There is a small obvious crater nearly in the middle of the rill, on its eastern shore. To the southwest of the crater *Hell*, B, at a distance of ⅓ of the diameter of this ring-plain, there is a well-defined crater, with a strong inner shadow and a bright wall, whose diameter is 1.6 *km.* SCHMIDT has mapped, to the northwest of *Hell*, B, a large crater in the position Long. — 5°.0, Lat. — 29°.7. The photograph depicts this as a very dark point, surrounded by a dark area, which gradually shades off, the point being the center of an obvious conical mountain. This summit-crater is 0.5 *km.* in diameter, and according to other Lick plates, lies in the center of a larger crater, whose diameter is 3.9 *km.* A fine rill runs through the summit-crater nearly in the direction of the meridian.

Visual Verification. The rill through *Hell*, B, was verified by GAUDIBERT on September 2, 1893, 4^h–5^h A. M., after several unsuccessful attempts. On the following night the rill could no longer be seen, and in general it is to be described as being optically difficult. (See *English Mechanic*, 1893, December 1, p. 328.)

Discovered 1892, March 1.

L. O. plate, 1888, August 27, ... P. S. T. *Age* = 20 days; (1).
To the northwest of the crater *Hell*.

SCHMIDT has drawn a large crater, *c*, in the line connecting *Hell* and *Hell*, B. West of the middle of this line SCHMIDT shows a semi-circular elevated formation. The photograph depicts, near the place of the latter, a large, round, dark spot, with wall-like surroundings. It appears to be a crater of 3.7 *km.* diameter. Let us call it x. In the middle, between x and c, there is another smaller crater of 1.3 *km.* diameter, with a fine rill east of it. Between c and x, but nearer to c, all the photographs plainly show a long elevation running outwards from *Hell*, B. This elevation is not given by SCHMIDT, however.

Visual Verification. M. GAUDIBERT, to whom I communicated the above description, succeeded in seeing the object x as a depression, surrounded by low walls, on September 3, 1893, at 4^h 45^m A. M., after some previous unsuccessful searches. (See *English Mechanic*, 1893, December 1, p. 328.)

Discovered 1892, March 1.

L. O. plate, 1888, August 27, ... P. S. T. *Age* = 20 days; (1 +).
To the south of *Birt*. *Thebit*, B.

On SCHMIDT'S map, Section VIII, there lies an easily seen crater (let us call it 1) southeast of *Birt*, in Long. — 10°.44, Lat. — 25°.39. Northeast of 1 there is a slightly smaller crater, which we may call 2. Finally, there is a third crater, 3, to the south of 1, which is only half as large as the latter. West of the line 1–3 the photograph shows an obvious, unknown crater (x), with an inner shadow and bright wall, whose diameter is 1.78 *km.* x is nearest like crater 3, but appears to be not so deep. The exact place of x is defined by the statement that x, 3, and 1 form an isosceles triangle with the base 1–3, the side x–1 being slightly greater than the distance 1–2.

Two different plates show to the east of x a faint, curved, rill-formation, 0.7 *km.* in width, which appears to extend to the ring-plain *Birt*. From the crater 1, a rill, passing through several small craters, also runs toward *Birt*. Between crater 1 and the line joining *Birt* with *Birt*, *b* (NEISON), lie four craters of about the same size (diameters 1.9 *km.*) in the form of a trapezium. Of these SCHMIDT has only drawn two, but these are not correctly placed.

These four craters can be found by joining 1 with *Birt*, then 1 with *Birt*, *b*, and by dividing each of these lines into three equal portions, thus obtaining four points of division. By going a little west from the two division-points of the line 1–*Birt*, we come to two of the four craters; and by going a little east from the two division-points of the line 1–*Birt*, *b*, we come to the other two. Fine rills pass through these four craters.

Visual Verification. The crater x was seen by G. WITT, in Berlin, on October 12, 1893 (in the last quarter), and by T. G. ELGER, in Bedford, on December 27, 1892 (first quarter). The latter observation was confirmed by W. H. MAW, in Kensington. (See *Astronomische Nachrichten*, no. 3130, p. 159; *Sirius*, 1894, February, p. 34, and *Memoirs of the British Astronomical Association*, vol. II, part II, p. 44. In the last-cited work, however, my description of x is not understood, and consequently the conclusion there given is incorrect.) In addition it should be remarked that x is easier to make out, photographically, in the last quarter than in the first, and this may be said to be the case visually, also.

Discovered 1892, March 1.

L. O. plate, 1888, August 27, ... P. S. T. *Age* = 20 days; (1 +).
In *Ptolemy*.

The crater A, in the northern interior of *Ptolemy*, has a small crater on its southeast wall. To the east of and near A lies a large, leaf-shaped rill-formation, with its point directed toward the northwest. The breadth of the leaf is about two diameters of A, and its length is about three diameters. Its west side appears to be parallel to the meridian. The axis of the leaf makes an angle of some 40° with the meridian. The Lick negative of 1892, November 10, $14^h\ 54^m\ 31^s$, P. S. T., shows near to the center of *Ptolemy* a large, circular crater-ring, with at least four crater-pits on its periphery. The diameter of this ring is 14.3 *km.* Within it there is a smaller, nearly concentric, ring of 5.3 *km.* diameter, and within the latter ring, somewhat to the east of its center, lies a crater of 1 *km.*, which is the crossing point of several fine rills. The craters A, *d*, and the last-named crater form a triangle, approximately isosceles, whose base is A–*d*, and whose altitude is somewhat greater than twice the diameter of A. Indications of the crater-ring, and of the crater-pits belonging to it, are to be found on other plates also. Toward the east border of the interior of *Ptolemy* there lies a cup-shaped hollow, similar to that north of A. Let us call it *e* (as in the *Memoirs* of the B. A. A., vol. II, part II, plate 1). From the center of *e* six or eight rills radiate to all sides. One of them runs to the crater *d*, and continues on the other side of *d*, in a northerly direction, as far as the wall. This rill, *e–d*, is confirmed by other photographic plates. South of *d*, and near to it, lies a crater 2.4 *km.* in diameter. According to the photographs the interior of *Ptolemy* contains many other similar craters, as well as different rills and lines of elevation, which cannot be well described without a diagram.

Visual Verification. GAUDIBERT verified the existence, by his observations of March 14, 1894, in the interior of *Ptolemy*, of several shallow depressions, subject, however, to rapid changes of visibility.

Discovered 1892, March 1; 1893, December.

L. O. plate, 1888, August 27, ... P. S. T. *Age* = 20 days; (1).
In *Alphonsus.*

In the western parts of the interior of *Alphonsus* there are several rills between the well-known rill, laid down by SCHMIDT on the northwest border, and the central mountain. One of them goes from the place where the crater-rill from *Arzachel* breaks through the wall of *Alphonsus*, runs next toward the northeast, and then bends toward the west base of the central mountain, where it terminates. A second rill originates east of the southwestern dark spot (in this place it also shows a faint connection with the first rill), goes northwesterly, and then winds its way nearly parallel, on the whole, to SCHMIDT'S rill, but nearer to the latter than to the central mountain. In the middle, between SCHMIDT'S rill and the central mountain, lies a third rill, which runs northwesterly and joins the second rill. This third rill is particularly interesting on account of its sinuosities, and because it seems to turn aside to avoid a low hill. Northeast of the central mountain, and at a distance of a diameter of this mountain, there is a small crater, which is to be found on several photographic plates.

Discovered 1892, March 1.

L. O. plate, 1888, August 28, ... P. S. T. *Age* = 21 days; (1 +).
Eratosthenes.

At the western base of the central mountain there is a plain rill. Imagine a meridian drawn through the center of this mountain. The rill begins at the south of the mountain, in the meridian, goes from there in a semi-circular arc around the southwest and west borders, and stretches alongside the mountain in its northern course. It ends north of the central mountain in a small crater, near the meridian line before described. In the southwestern part of this rill there appears to be a branch rill toward the southwest.

South of this branch there lies, at the border of the floor, a minute crater of 0.5 *km.* diameter, from which rills radiate. According to the Lick plate of August 27, 1888, there is shown on the inner northwest wall, along its whole breadth, a remarkable wave-shaped rill, with a southeasterly course, which turns aside from the elevations of the wall (forming the boundary of the shade of the transverse elevations in that locality), and which, after an inflection toward the south, debouches in an oval formation at the foot of the wall. Its course can be followed to the middle of this formation. The western longer side of the latter lies on the inner border of the wall, and is 1.6 *km.* in length by 1.2 *km.* in width. In the direction of the entrance of the rill into this formation, still another short rill-branch toward the north is shown. A part of the serpentine rill described, together with the oval formation, can be certainly seen on the Lick plate of 1893, August 3, $15^h\,23^m\,13^s$, P. S. T.

The interior of *Eratosthenes* shows several minute craters; among them is one on the inner north wall, nearer to the crest than to the foot, whose diameter is 0.5 *km.* From this crater two fine, nearly parallel, lines extend toward the south. According to the last-named plate there is, to the north of *Eratosthenes* in *Mare Imbrium*, a crater not drawn by SCHMIDT, which may be described as follows:

North of the mountain *Wolf*, in the eastern *Apennines*, there is a mountain formation (x) resembling a ring-plain. To the south of x lie two obvious craters, the westernmost of which I shall call A, and the other a. Southeast of A a lie three small craters, almost of the same size. Call the westernmost of the three, b. Now, bisect the line a . . . . b, and measure off this distance from a in the same direction, toward the northwest, and we arrive at the (new) crater, whose diameter is 2.5 *km.* The reality of this object is verified by a second Lick plate of 1891, July 14, $8^h\,16^m\,26^s$, P. S. T.

Discovered 1892, March 11; 1894, May 23.

L. O. plate, 1890, September 22, $8^h\ 3^m$, P. S. T. *Age* = 8 days 20 hours; (1 +). To the northwest of *Hyginus*.

To the east of *Boscovich*, at a distance of one diameter of *Boscovich*, there is an obvious crater (let us call it *c*) of 4.2 *km*. diameter. MAEDLER has drawn it in exactly the correct position. It is missing in SCHMIDT'S map. South of *c*, near the *Hyginus*-rill, lie the two craters called *a* and *b* by KLEIN. Call the middle-point between *a* and *b*, *m*. Then, according to the photographs, and also according to MAEDLER, the distance *m* . . . . *Hyginus* is almost the same as the distance *m* . . . . *c*, and the angle of elongation for *Hyginus* and *c*, seen from *m* is 110°. Northeast of *Hyginus*, at a distance of almost two *Hyginus*-diameters, there lies, on the western shore of the great rill, a plain crater of 2.1 *km*. diameter, from which several rills radiate. According to the Lick plate, 1891, July 13, $8^h\ 24^m\ 57^s$, P. S. T., one of them runs to KLEIN'S crater, N. This rill branches, however, at the distance of one *Hyginus*-diameter from the great rill, toward the northwest. It traverses, to the south of the λ-rill, which lies near *γ* (NEISON),* in a westerly course, the two long elevations which lie nearly parallel to the northern *Hyginus*-rill, and divides, exterior to the western elevation, into two parts. One of these parts goes through the crater *c;* the second part goes north of *c*, at the distance of a *Hyginus*-diameter, as far as *Boscovich*. To the north of *c* this second part again subdivides and sends out a rill-branch, still very plain, parallel to the northeast wall of *Boscovich*. The eastern leg of the λ-rill shows a rill-like prolongation in a northeasterly direction, which runs as far as the great *Hyginus*-rill. Northeast of *Hyginus* there lies, beyond the eastern shore of the rill, at a distance of four *Hyginus*-diameters, a plain conical mountain, on whose summit there is a crater of 1.2 *km*. diameter.

Discovered 1892, July 4; 1894, March.

L. O. plate, 1890, September 22, $8^h\ 3^m$, P. S. T. *Age* = 8 days 20 hours; (1 +). In the neighborhood of *Birt*.

On the western roof of the long straight mountain-wall *β* there are several rill-like lines. A configuration forms an isosceles triangle, with the base in the wall *β*, and the vertex west of *β* in the line joining *Birt* and *Thebit*, *x*. The base is three diameters of *Birt;* the altitude, one. The northern side of the triangle appears to be a crater-rill, which runs to the double crater southeast of *Thebit*, *x*. The southern side produces the impression of a shallow valley. This side extends toward the south to a crater on the edge of the mountain-wall, from which crater numerous rills radiate. To the east of the elevation, H, a rill (or a low elevation, it is not easy to decide which) runs to the south; at first it converges toward the wall β, then, however (in the line x to *Nicollet*), bends, making a knee, to the southwest, as far as the double crater just mentioned. SCHMIDT has a crater in the middle, between H and the wall β. This crater is shown to be united with the crater D, at the north end of the wall β, by a rill which is most easily seen in the vicinity of D. West of H, at a distance of two-thirds of the diameter of *Birt*, there is a plain crater of 3.7 *km.* diameter, which is not given by SCHMIDT. According to the Lick negative of 1891, July 14, $8^h\ 16^m\ 26^s$, P. S. T., the latter is connected, toward the south, to a similar crater-formation (more extended, however), so that the whole makes the impression of a crater-valley. From the northern outer wall of *Birt*, a clear winding rill goes northward, and branches to the west, at a distance of one diameter of *Birt*. This branch cuts through the wall β, and runs to the northern side of the triangle described above. The principal branch can be followed, even into the crater D. At the origin of this rill, and somewhat to the west of it, a small crater lies on the north wall of *Birt*. According to the Lick negative of 1893, August 3, $15^h\ 23^m\ 13^s$, P. S. T., there is also another rill, which runs from the northwestern outer wall of *Birt* toward the west, cuts through the wall β, and then goes, in an arc, to the south, through the gap in β, which stretches westward from the so-called sword-handle. The southern prolongation of the well-known rill, lying east of *Birt*, is confirmed by the photograph, as well as the rill-valley which runs eastward in the same selenographical latitude as *Birt*.

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* See *Himmel und Erde*, October, 1892, p. 40.

The northern part of the known rill, just mentioned, has its principal course parallel to the mountain-wall B. SCHMIDT and KLEIN (*Fuehrer am Sternenhimmel*, p. 417) have drawn it converging toward B, while NEISON has represented it as diverging. Moreover, it does not end in the double crater drawn by SCHMIDT in the line D to *Nicollet* (which the photographs represent as a rather long crater-valley), but is prolonged here in two branches, two diameters of *Birt* farther. The eastern branch varies very little from the general east direction of the rill; the western, on the other hand, has a northwesterly direction. According to the Lick plate of 1893, August 3 (already cited), a clear rill runs from the crater-valley, above mentioned, to the north wall of *Birt*. This plate not only shows the small crater lying southeast of the crater-valley, but shows also, west of the valley, a somewhat larger unknown crater, whose right position is described as follows:

Join D and *Birt*, *b*, by a right line, and divide the line into three equal parts; the division-point nearest D falls on the place of the crater. This crater can be recognized on other plates also. According to the Lick plate of 1892, November 10, $14^h\ 54^m\ 31^s$, a gently curving rill runs from the south wall of *Nicollet* toward the south, about parallel with the line of the western heights. This rill in addition has, at *Nicollet*, a western branch, which runs through a small crater, and which makes a long loop with the first-named rill. These rills are confirmed by several photographic plates.

Visual Verification. The triangle above described, which is joined to the mountain-wall B on the west, was independently found and observed by GAUDIBERT on April 13, 1894. He conceived it to be a shallow depression of the slopes. The crater lying west of H may be identical with the small circle drawn by KLEIN. (*Op. cit.*, p. 417.)

The parts of the rill running from the north wall of *Birt* which lie nearest to this crater, were independently seen by J. KRIEGER on July 15, 1892, and July 6, 1893. The course of this rill is, however, not so straight as represented in the drawing in *Sirius*, 1893, September, plate IX.

Discovered 1892, July 6; 1894, March.

L. O. plate, 1888, August 15, . . . P. S. T. *Age* = 8 days; (1). *Flammarion.*

On GAUDIBERT'S lunar chart, the large crater lying northeast of *Herschel*, which has on its east wall the crater *Moesting*, A (so important for measures of the libration), is called *Flammarion*. Northwest of the west wall of *Moesting*, A, at a distance of 1.5 diameters of A, there is a small, dark crater, 0.9 *km.* in diameter, from which three rills radiate in the general directions east, north, and west. The last is the longest, and extends beyond the center of *Flammarion* (see *L'Astronomie*, 1893, April, p. 133).

Visual Verification. The small crater, above mentioned, from which the rills radiate, had already been seen by GAUDIBERT on December 4, 1886. (See *L'Astronomie*, 1894, February, p. 55.) The western rill, as well as a branch of it running to the south (which lies west of the small crater, and which is easily seen on my 20-fold enlarged drawing of *Flammarion*), was confirmed by NIELSEN on April 24, 1893, with the Copenhagen refractor. (See *The Observatory*, 1893, December, p. 410.)

Discovered 1892, December 18.

L. O. plate, 1888, August 15, ... P. S. T. *Age* = 8 days; (1 +). Near *Flammarion*.

On the north wall of *Herschel*, *a*, lies a crater of 7.0 *km.* diameter, which is not given by SCHMIDT. Let us call it x. Northeast of this place, SCHMIDT draws two large craters, nearly of the same size and close together. Call the northern one y. The photograph shows y almost of the same size as x, and exhibits a considerably smaller crater attached to y on the south. Southeast of *Moesting*, A, at a distance somewhat greater than the diameter of this crater (and west of the point of intersection of the forked elevation opening toward the south) lies a long crateriform object, which we may call z. The major axis of z lies in the meridian, and is 8.3 *km.* long. Its character is that of a shallow crater-valley. It is not given by SCHMIDT. MAW discovered, to the west of x and near to it, a sharply defined small crater, whose diameter is about one-third of that of *x*. This can be certainly seen on four of the Lick plates in the collection at Prague. (See *Memoirs of the B. A. A.*, vol. II, part II, p. 45, plate IV; *L'Astronomie*, 1893, February, p. 57, and 1893, April, p. 133; *The Observatory*, 1893, December, p. 410.)

Visual Verification. *x* and *z* have been verified by ELGER, WITT, MAW, WILLIAMS, myself, and others, and the small crater attached to *y* has been verified by WITT and MAW.

Discovered 1892, December 18.

L. O. plate, 1888, August 15, ... P. S. T. *Age* = 8 days; (1 +).
East of *Reaumer*.

At the south end of an elevation which, at a distance of one diameter of *Moesting*, A, extends east of *Reaumer*, there lies a larger, very plain, crater, whose diameter is at least 4.2 *km*. This crater is lacking in SCHMIDT'S map, which is all the more remarkable as it is to be found on every one of the photographic plates whose exposure-time is at all suitable. Its approximate position on SCHMIDT'S Section I would be, *Longitude* = — 0°.6; *Latitude* = — 3°.0. Near to it, and to the southeast, there is a somewhat smaller crater (3.2 *km*. in diameter), which is likewise verified by several plates. Again, two other craters, of the order of the one last named, lie north of the first crater, on the western border of the elevation already mentioned, at small distances.

Visual Verification. The first named crater was, according to a letter from GAUDIBERT, observed by him as early as February 24, 1874, and again on May 15, 1883. The two craters lying north of it were independently discovered by WITT, in Berlin, on March 25, 1893, with the 12-inch refractor of the Urania Observatory.

Discovered 1892, December 20.

L. O. plate, 1891, July 28, $15^{h}\,49^{m}\,16^{s}$, P. S. T. *Age* = 23 days 8 hours; (1 +).
To the west of the *Riphaeus Mountains*.

West of the southern parts of the *Riphaeus* mountains lies the crater *d*, with a diameter of 7.6 *km*. Still farther west there is a crater of about the same size, which we shall call *e*, while we shall call *f* the crater southeast of *d*, at the southern end of the *Riphaeus* chain. On the plate cited at the head of this paragraph (I) there is to be found a crater of 2.3 *km*. diameter, joined to *d* on the north, whose reality is verified by a second plate of August 17, 1888 (II). This crater is missing in SCHMIDT'S map. According to I we may characterize the following objects as new: A large crater-pit east of *d*, through which goes a rill in the direction southwest-northeast; from this pit a crater-valley of considerable width runs to the north. Also southwest of *d*, a plain rill-formation extends in the direction southeast-northwest. The crater *f* appears to have a minute crater on its north wall, which is shown plainly on II, but merely by a faint outline on I. Both plates show *e* to be larger than δ, while SCHMIDT gives the contrary relation.

Visual Verification. The northern crater connected to *d* was seen by GAUDIBERT on March 16, 1894, in its correct size and place, although the unfavorable atmosphere did not allow him to verify its crater character. (See *English Mechanic*, 1893, December, p. 328.) The above-mentioned rill-like formation on the southwest wall of *d* was verified by its course by WILLIAMS on September 4, 1893, as a fine, black line. (See *The Observatory*, 1893, December, p. 411.)

Discovered 1893, February 19.

L. O. plate, 1890, November 17, $6^h\ 8^m\ 35^s$, P. S. T. *Age* = 5 days 12 hours; (1 +). In *Capella*.

On the peak of the central mountain of *Capella*, GAUDIBERT discovered a small crater on May 24, 1890, and on the western declivity of the same mountain, a still smaller crater was seen March 15, 1891. Both craters are plainly visible on the plate named above (I), and also on a second plate taken August 31, 1890, at $14^h\ 27^m$, P. S. T. (II). The summit-crater has a diameter of 1.34 *km.*, the lateral crater one of 0.76 *km.* Both Lick plates are in good agreement in showing, moreover, in the eastern vicinity of the summit-crater, a minute crater of only 0.51 *km.* in diameter. The plate I also shows in the western neighborhood of the same GAUDIBERT crater, two small, clear craters, each of 0.70 *km.* diameter. Also, a fine rill, which runs from the summit-crater toward the southwest, and which farther on divides into two branches, is certainly visible on both I and II. Besides this, the central mountain is cut through by several rill-like or trough-like traces, which radiate from the summit-crater. (See *L'Astronomie*, 1893, September, p. 332; *Sirius*, 1893, August, p. 169; *Publ. A. S. P.*, 1893, p. 158.)

Discovered 1893, May 1.

L. O. plate, 1890, November 16, $5^h\ 53^m$, P. S. T. *Age* = 4 days 12 hours; (1 +). *Taruntius*, C.

There is a crater on the north wall of *Taruntius*, which MAEDLER calls C. In the interior of C, three different Lick plates show a central formation of 2.2 *km.* in size, in whose center the Lick plate of 1890, August 31, $14^h\ 27^m$, P. S. T., shows an excessively small crater of 0.25 *km.* diameter. (See *Sirius*, 1893, August, and *Publications Astronomical Society of the Pacific*, 1893, no. 31.)

Discovered 1893, May 5.

L. O. plate, 1891, July 14, 8^h 16^m 25^s, P. S. T. *Age* = 9 days 0 hours; (1+).
In *Schroeter*.

On the northern interior border of *Schroeter* there are two crater-pits, which can be seen, also, on two other Lick plates. Let us call the western one *x*, the other *y*. *x* lies somewhat farther south than *y*, and has a diameter of 2.3 *km*., while *y's* diameter is 1.9 *km*. Their distance apart is somewhat less than twice the diameter of *x*. A plain rill-formation is connected with *x* on the south; it traverses a considerable length of the interior of *Schroeter*. Its direction is, in general, south; and it is slightly convex toward the east. This rill is also verified by several plates. The crater A, in the southwestern interior of *Schroeter*, appears to have a central elevation.

Discovered 1893, May 18.

L. O. plate, 1891, October 12, 7^h 29^m 9^s, P. S. T. *Age* = 10 days 2 hours; (1+).
Near *Moesting*.

Outside of the northwest wall of *Moesting* there is a strongly-marked rill, with well-defined walls, running between this ring-plain and the crater in this place (called *m*). Its direction is nearly meridional; and, somewhat to the north of *m*, it divides into two short branches. In the selenographic latitude of the southern half of the crater *m*, it bends toward the southwest, and runs to the north end of the elevation β (which lies west of *Moesting*), where, in this course, it sends out two short branches toward the southeast and south, respectively. Outside of the south wall of *Moesting* there is a second long rill, which there traverses the northernmost crater of SCHMIDT'S crater-rill, where it appears curved, with its convex side toward *Moesting*, and in its course from west to east, runs, on the one hand, up to the elevated region β, and, on the other hand, to the south of *Soemmering*. A third rill-formation runs along the eastern interior border of *Moesting*, and goes through a few small craters. The largest of the craters lies on the inner northeast border, and has a diameter of 1.5 *km*. This rill seems to be connected with the second of the above-mentioned rills, which crosses the rill-crater.

Discovered 1893, May 18.

L. O. plate, 1891, July 14, ... P. S. T. *Age* 9 days 0 hours; (1).
In *Schroeter*, *a*.

North of *Schroeter* lies the crater *a*. SCHMIDT has drawn a small crater on its eastern interior border. Not only was this seen on the plate cited as a sharp round contour of 1.4 *km*., but there was also discovered, on the south wall, a plain, circular, dark, crater of about the same size. Its diameter is 1.3 *km*. Three smaller crater-formations, about half this size, lie on the west, north, and east walls, respectively. There also appear to be a few rills traversing the crater *a*.

Discovered 1893, May 30.

L. O. plate, 1893, August 3, $15^h\ 23^m\ 13^s$, P. S. T. *Age* = 21 days 22 hours; (1 +). Between *Reaumer* and *Moesting*.

A 24-fold enlargement from the plate above cited, of the neighborhood of *Flammarion*, shows the following ten craters in the north, northwest, and northeast of that crater. None of them is given by SCHMIDT. For each crater I give below, the selenographic longitude (west is positive); the corresponding latitude (north is positive) according to the meridians of SCHMIDT'S chart; and the diameter, δ, in *kilometers:*

1. Long. — 3°.95; Lat. — 0°.7; $\delta = 3.5$. This lies in the selenographic latitude of the center of *Moesting*, and west of it by three of *Moesting's* diameters.

2. Long. — 0°.25; Lat. — 0°.5; $\delta = 3.4$. It lies southeast of *Reaumer*, B.

3. Long. — 7°.1; Lat. — 1°.8; $\delta = 3.3$. It is situated in the middle between *Moesting* and the crater *Moesting*, *b*, to the southeast.

4. Long. — 2°.65; Lat. — 0°.7; $\delta = 2.7$. This object is probably a crater, but it is not possible to be quite certain.

5. Crater-pit, lying north of SCHMIDT'S crater, in Long. — 0°.55; Lat. = 1°.45 (outside of the northeast wall of *Reaumer*). The diameter of the pit is 2.4 *km.*

6. Crater-pit, lying northwest of SCHMIDT'S crater mentioned in § 5. $\delta = 2.4$.

7. North of crater 1, and about a diameter of this crater distant from it. $\delta = 3.2$.

8. Long. — 1°.4; Lat. — 1°.3; $\delta = 2.1$. There seems to be a similar crater, of the small size, south of 8, on the western declivity of the elevation here situated.

9. Long. — 1°.7; Lat. — 0°.9; $\delta = 1.8$.

10. Long. — 2°.2; Lat. — 0°.4; $\delta = 1.8$.

Craters 1, 2, 3, 4 can be well seen on the Lick plate of 1891, July 14, $8^h\ 16^m\ 26^s$, P. S. T. 1 and 2 are also visible on many other plates. 1 is very plain, and is but little smaller than the crater which lies on the inner north border of *Flammarion*. No. 8 is difficult on the plate above cited, but, on the other hand, it is easily seen on that of 1892, November 10, $14^h\ 54^m\ 31^s$, P. S. T.

Discovered 1894, May 23.

L. O. plate, 1893, August 3, $15^h\ 23^m\ 13^s$, P. S. T. *Age* = 21 days 22 hours; (1 +).
Southwest of *Plato*.

A 24-fold enlargement of *Plato* and its vicinity has been made from this negative. There are at least six craters on the negative which are not shown in SCHMIDT'S map, Section XV. Their positions and magnitudes are noted below:

1. Long. — 5°.35; Lat. + 47°.45; $\delta = 2.3$ *km.* This crater is south of the double-crater *i.*

2. Long. — 6°.9; Lat. + 47°.2; $\delta = 2.2$. North of crater *c*. Connected with it, to the west, there appears to be a somewhat smaller crater, $\delta = 2.0$. Between *c* and 2, also northeast of *c*, there may be several craters scarcely half so large. A rill-formation goes from *c* toward the north up to the elevation K; another runs to the northwest in the direction toward *i.*

3. Long. — 5°.3; Lat. + 46°.25; $\delta = 2.3$. This lies southeast of SCHMIDT'S group of three small craters on the west slopes of the height *m*, in this place.

4. Long. — 5°.3; Lat. + 46°.55; $\delta = 1.5$. This lies north of the object No. 3, also on the west slopes of *m*. A somewhat larger crater, $\delta = 2.3$, seems to be connected to No. 4 on the west.

5. Long. — 6°.15; Lat. + 45°.65; $\delta = 2.0$. This lies on the southern crest of the eastern branch elevation of *m.*

6. Long. — 6°.9; Lat. + 45°.2; $\delta = 2.0$. This also lies on the southern crest of the branch elevation mentioned under No. 5.

Craters 1, 2, and 3 are also shown in the Lick negative of 1892, November 10, $14^h\ 54^m\ 31^s$, P. S. T.; crater 1 especially well.

Discovered 1894, May 24.

The 24-fold enlargements, made at Prague (Moon's diameter, X feet), are admirably suited for the discovery of new features on the Moon. It is only necessary to enlarge the same region of the Moon from different original plates, and to carefully compare the different enlargements among themselves, and with SCHMIDT'S chart. Formerly, the study of the Lick plates demanded a wearisome examination with magnifying eye-pieces, each giving but a relatively small field of view, of the necessary sharpness; now, however, the process is carried back to the much more convenient examination of a sufficiently extended landscape with the unassisted eye. Each enlargement affords such discoveries in considerable numbers; and also enables the positions of SCHMIDT'S 2-*meter* chart to be improved. These corrections will not be published until the corresponding plates are issued. I may add here that, by such comparisons, I have lately found a large, crater-like depression, of 6 *km.* diameter, in the middle of *Archimedes*, which has been confirmed by GAUDIBERT'S visual observations; that the interiors of *Archimedes* and

Plato contain fine rills, which need an accurate study; and that the Lick negative of 1893, August 3, $15^h\ 23^m\ 13^s$, P. S. T., shows to the south of *Archimedes*, between the elevations λ and Δ, a sinuous rill-formation with many branches, which runs into a sunken valley. This seems to be of the same character as the rills, previously referred to, in the southern interior of *Petavius*, in the western interior of *Aplhonsus*, and on the inner northwest wall of *Eratosthenes*.

CONCLUSION.

After I had once satisfied myself of the high value of the Mount Hamilton plates to selenography, my sole aim, in the work which has been presented in the foregoing chapters, has been to exhibit what these plates did, in fact, contain. This has been attempted in various manners: By the extremely laborious method of enlarged drawings; by direct enlargements by photography; and by the most assiduous comparisons of different plates between themselves. I feel that I may confidently leave it to the reader to decide if I have been successful in my attempt. That I have spared no pains in this, will be realized by any one who may go over the same ground after me. If any one should doubt the interpretations here given of the negatives, I ask that he should spend as much time in their study as I have done, and that the examination should be made in an equally thorough manner. Such a study will, I am confident, lead to the judgments which I have formed as to the extreme value of the splendid negatives of the Lick Observatory.

These negatives constitute, in fact, a very considerable step forward in the field of lunar topography, not only on account of their faithfulness and truth as representations of the Moon's surface, but also because it is now possible for the selenographer to study this topography in the most convenient and thorough manner from a series of such pictures which exhibit all the various phases.

It is precisely on this account, namely, that the photographs of the Moon in its various phases can be studied *at one time*, and that it is not necessary to wait, as in visual observations, for a desired phase to present itself; it is precisely on this account that the photographic method presents priceless advantages. It is not by any means to be concluded that visual observations of the Moon are no longer necessary. The very difference of the optical and chemical efficiency of the rays of light calls for visual observations with the telescope, to compare with the photographic representations.

To supply the needs of selenography both methods must be perfected, and each must support the other.

L. WEINEK.

Prague, 1894, June 6.

PART II.

REPORT ON SPECIMENS OF CROWN AND FLINT GLASS

BELONGING TO THE

LICK OBSERVATORY,

AND

MANUFACTURED BY THE MESSRS. FEIL.

BY C. S. HASTINGS, PH.D.,
Professor of Physics in the Sheffield Scientific School of Yale University.

OCTOBER, 1887; APRIL, 1889.

REPORT ON SPECIMENS OF CROWN AND FLINT GLASS BELONGING TO THE LICK OBSERVATORY, AND MANUFACTURED BY MESSRS. FEIL.

By C. S. Hastings, Ph.D.,
Professor of Physics in the Sheffield Scientific School of Yale University.

I.

VARIETIES OF GLASS.

In June, 1883, the writer received from Mr. Plum, of the Trustees of the Lick Observatory, a piece of glass which he had obtained from Feil in Paris, as a fragment of the material of the great objective. A prism was made of this by Mr. Brashear. It is denoted by *g* in the following table of densities. At the same time a large piece of flint glass, said to be a portion of the material used in the Vienna objective, was given me; marked *x* in the table. In November, 1885, a rough crown prism and a disc of flint were sent me from Madison by Professor Holden. They were marked (doubtless by the manufacturer) 1734 and 1588, respectively. In the table of densities this flint is indicated by *a* and the crown by *b*. On December 5th a box from Cambridge was received containing two crown discs marked 1734, one flint disc marked 1588, and an irregular piece of crown marked 1720. The flint disc is indicated in the table by *c*, the crown discs by *d* and *e*, and the irregular fragment by *f*. The numbers proper to the material actually employed in the construction of the great objective are unknown, but they are believed to be flint 1588 and crown 1734; Feil, however, writes that the "third disc," sent about April 1, is 1720; first crown sent September, 1885, is 1743; and flint 1588. It will be noticed that the number 1743 does not occur elsewhere, and is without doubt a mistake. Finally the Messrs. Clark received a large box of glass from Feil late in July, 1885, with some small discs, said to be of the same material as the large objective, but unmarked. Of these the Clarks took a crown and flint, and constructed a 4½-inch objective as a preliminary step in the construction of the great one.*

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* Note by E. S. Holden.—From copies of letters from the Messrs. Feil to the Messrs. Clark, in my possession, I find that about 1882, April, the flint disc of the 36-inch objective was made. It is No. 1588. This is from the same *fonte* as the flint lens of the Nice objective made by the

In order to find which of these materials enters into the construction of the objective, it was first necessary to find whether the numbering of the pieces in my possession was consistent. For this purpose the specific densities of all the pieces were determined. This method was deemed sufficient, since this constant differs notably in different specimens of optical glass rated commercially alike. Their values are as follows:

Specimen.	Number.	Sp. Den.	Variety.
a	1588	3.621	flint
b	1734	2.509	crown
c	1588	3.620	flint
d	1734	2.512	crown
e	1734	2.510	crown
f	1720	2.571	crown
g	. . .	3.710	flint
x	. . .	3.653	flint

Of these, *a* and *c* are obviously the same, and were both marked 1588. The number 1734 was common to *b*, *d*, and *e*; *f* is No. 1720, while *g* and *x* are at once disposed of.

The conclusion is: 1st, that the flint of the great objective is No. 1588; 2d, that the crown is No. 1734; 3d, that the crown 1720 was that to be used for the purpose of correcting the objective for photography. If any doubt remains concerning the crown glasses, it can be readily eliminated by weighing the crown lens and calculating its density, since the two varieties differ in density by nearly 2½ per cent.

II.

PRISMS.

A prism was made of each of the three varieties of glass in question. For crown 1734 alone was there a piece quite large enough for the purpose, the rough prism yielding a finished 60° prism, with circular faces of 3.4 *cm.* diameter. The best that could be made of the irregular fragment of crown 1720 was a 60° prism

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Messrs. HENRY. The crowns 1720 and 1734 were made about the same time, and probably are of the same *fonte*. 1734 (not 1743, as FEIL writes, by a clerical error) was chosen as the crown for the 36-inch objective. 1720 was sent to the CLARKS, on approbation, as a photographic corrector, and broke in their hands. In July, 1885, 4½-inch discs, which FEIL reported to be the same as 1734 and 1588, were sent to the CLARKS, and were by them made into an objective. Finally in August or September, 1887, crown 1937 was secured for a photographic corrector; and a plate of this was sent to Dr. HASTINGS in October, 1888. The 4½-inch objective spoken of above is in the possession of the Lick Observatory.

of 2.4 *cm.* aperture. Of the flint 1588 a satisfactory prism of like angle and aperture 2.6 *cm.* was made by cutting two triangular pieces from one of the discs and cementing them together. Only rigidly flat faces in the smaller prisms would secure the requisite definition, namely, that the D line should be so clearly separated that it would be easy to determine the angle of deviation for either component.*

III.

INSTRUMENT.

A reduction of a considerable series of observations made with the spectrometer belonging to the physical laboratory of the Sheffield Scientific School showed that it would be impossible to obtain the desired accuracy without a more exact reading than that from the mean of the four verniers. The telescope and collimators were therefore adapted to a new circle of glass, reading by two micrometer microscopes. The circle was 21 *cm.* in diameter, divided into single degrees only, except that four degrees, separated from each other by arcs of a quadrant, were subdivided into 10 parts. As both the telescope and the table which carries the prism may move independently of the circle, it is always possible to have one end of the arc to be measured fall near a degree mark, and the other within one of the subdivided degrees. The micrometer microscopes were provided with screws of sixty threads to the inch, having heads divided into 100 parts. The microscope objectives were of such focal length that one revolution of the screw corresponded to approximately one minute of arc, and the magnifying power was about 220. The power is without doubt unnecessarily high, but the flatness and adjustment of the plate were such that it was not found inconvenient. The probable error of a single setting of either microscope was found to be a little less than a half division of the head, *i. e.*, than ± 0″.3; but as the errors of pointing with such small apertures were considerably greater than this, as well as the variations due to slight changes in temperature and barometric pressure, the readings were made to half divisions only.

In dividing the circle no care was taken to secure great accuracy, because it was proposed to determine the absolute error of every line. There are therefore large systematic errors, rising to 42″, but the probable accidental error is about 5″ only. It is to be emphasized, however, that *all* errors not eliminated by the mean of the readings of the two microscopes are treated as accidental errors, hence all the measured angles given below are corrected by the amounts derived from the investigation of the circle.

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* These prisms were returned to the Lick Observatory in 1887, November. E. S. H.

The method of determining the errors of the divisions was as follows: Two auxiliary microscopes, placed at opposite sides of the circle, were firmly attached to the iron base of the instrument at a convenient angular distance from the fixed microscopes; then, by bisections and trisections of the arcs, the errors of all diameters at intervals of five degrees were determined to a degree of accuracy expressed by a probable error of 0".5. In order to eliminate errors due to character of the illumination, the readings were made with the fixed microscope reading the desired angle, then reading again with the circle turned 180°. At every change of the auxiliary microscopes the errors of run of all the screws were re-determined, although those of the fixed microscopes were practically constant. Periodic errors in the screw were found to be insensible, as would be anticipated from the construction of the micrometers and the high power of the objectives of the microscopes.

Frequent checks were obtained by forming equations of condition from the sums and differences of arcs thus determined, and if a residual as large as 1" occurred (a very unusual case), the arc or arcs were re-determined. After thus determining the values of every fifth degree line with the accuracy indicated, the corrections for all the angles used in the observations for the indices of refraction were obtained by five repetitions by means of the auxiliary microscopes, taking, of course, all the precautions described. If the angle happened to be an aliquot part of the circle, it was repeated to a return to the same line. Here again, equations of condition for all lines but the last one measured, were obtained by adding each arc to the interval 0 to 1 and comparing the sum to the value derived for that sum by direct observations. These operations were continued until the probable error of the determination was reduced to 0".2. It may be noted here that afterward, when a suspicion of error which arose in comparing the indices of the different prisms led to a re-determination of two of the lines, the corrections found did not differ in either case by as much as 0".1 from those already accepted. The origin of the suspicion was an erroneous temperature correction.

The objectives of the telescope and collimator of the instrument have apertures of 2.7 *cm.* and focal lengths of 25 *cm.;* the focal length of the collimator, however, was virtually increased about three times by the use of a concave lens so as to improve the character of the spectral lines. The magnifying power uniformly used in pointing on the Fraunhofer lines was 40.5, which, though unpleasantly great, was found to yield a little greater precision than a lower power. At the beginning of the observations it was found necessary to protect the telescope-tube, by a paper screen, against radiation from the face when reading the microscopes. This precaution would have been less indispensable if the tube had not been unusually thin.

IV.

ANGLES OF PRISMS.

In the determination of the prism angles the fixed collimator was replaced by the telescope, which carried a *quasi*-collimating eye-piece giving a power of 19. The peculiarity of the eye-piece is that it gives a bright reflection from the surface of the prism without any admixture of light from the surfaces of any of the lenses of the telescope.* By means of a plate of glass with plane and parallel sides the line of collimation of the telescope was rendered strictly perpendicular to the axis of the instrument, and then the axis of the prism table was adjusted so as to be accurately parallel to that of the instrument. Replacing the glass plate by a prism, the latter was adjusted by the proper leveling screws, so that the polished surfaces were parallel to the axis; then the supplement of the angle of the prism was determined by reading the position of the circle, first, when one face reflected the image of the line in the collimating eye-piece to the eye, and then when the other was in the same position. As the prisms had purposely been ground to an angle very near 60°, it was only necessary to repeat the angle three times in order to eliminate all errors of graduation. The table below gives the results of these observations; that is, the differences observed between the supplement of the angle of the prism and 120°. No observations were rejected.

TABLE I.

	Crown 1720.	Crown 1734.	Flint 1588.
	— 14″.71	+ 57″.96	+ 48″.11
	15 .72	58 .82	48 .83
	18 .09	56 .48	48 .44
	18 .24	+ 56 .84	50 .63
	20 .03		+ 50 .35
	18 .78		
	17 .37		
	14 .92		
	13 .84		
	14 .64		
	16 .22		
	13 .26		
	— 12 .91		
$180° - \alpha = 120°$	— 16.06 ± 0.42	+ 57.97 ± 0.36	+ 49.27 ± 0.34

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* This eye-piece and the method of using it are given in a paper on the Influence of Temperature on the Optical Constants of Glass. *Amer. Jour. Sci.*, vol. XV, p. 269.

The angles (α) of the several prisms are therefore:

Crown	1720;	60° 0′ 16″.06 ± 0″.42
Crown	1734;	59 59 2 .03 ± 0 .36
Flint	1588;	59 59 10 .73 ± 0 .34

V.

OBSERVED ANGLES OF DEVIATION AND RESULTING INDICES OF REFRACTION.

In order to determine the double angle of deviation corresponding to a selected Fraunhofer line, the prism was carefully adjusted on its table so that its sides were accurately parallel to the axis of the instrument, and at the same time perpendicular to the plane defined by the lines of collimation of the telescope and collimator. An adjustment not less essential is that which makes the beam of light transmitted by the prism traverse the objectives of the telescope and collimator quite centrally when set for minimum deviation, both right and left. When these conditions were assured the approximate double angle of deviation was found, and then the telescope was changed with reference to the circle so that lines indicating the extremities of this angle would fall near the zero points of the two microscopes. The collimator was always focused for the particular wave-length measured. A series of readings was then made, and the barometric reading and temperature of the prism recorded with them. The following tables give these measures and the results deduced from them. *All* observations are included, with the exception of a group made after one side of the plate had been inadvertently exposed to sunshine for about half an hour.

In these tables, the first column gives the line; the second, half the observed angle; the third, the resulting index of refraction; the fourth, the barometric reading; the fifth, the temperature; the sixth and seventh, the corrections necessary to reduce to a standard pressure and temperature of 30 inches and 20° C., respectively; and finally, the eighth, the reduced value of the index of refraction. The methods by which the two corrections named were derived will be given further on.

TABLE II.

Crown 1720. $\alpha = 60^\circ\ 0'\ 16''.06 \pm 0''.42$.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n	
A	38° 30′ 9″.02	1.515107	29.95	24.0	— 1	+ 6	12	1.515116 ± 0.9
	9 .86	10	29.95	24.1	— 1	+ 6	15	
	14 .11	23	30.30	14.0	+ 4	— 10	17	
	9 .47	08	30.45	21.5	+ 7	— 2	13	
	11 .52	15	30.45	21.5	+ 7	— 2	20	
	11 .11	14	30.45	21.5	+ 7	— 2	19	
B	38° 40′ 35″.82	1.517089	30.20	23.2	+ 3	+ 5	97	1.517097 ± 1.0
	35 .69	88	30.45	22.5	+ 7	+ 4	99	
	34 .10	83	30.45	22.5	+ 7	+ 4	94	
C	38° 46′ 0″.17	1.518113	29.95	24.2	— 1	+ 6	18	1.518115 ± 2.2
	1 .67	117	29.95	24.5	— 1	+ 6	22	
	45 55 .66	098	30.45	22.0	+ 7	+ 3	08	
	56 .59	101	30.45	22.0	+ 7	+ 3	11	
D_2 . . .	39° 0′ 24″.59	1.520837	29.95	23.7	— 1	+ 4	40	1.520850 ± 1.8
	31 .46	59	29.95	23.7	— 1	+ 4	62	
	27 .65	47	29.95	23.7	— 1	+ 4	50	
	29 .16	52	29.95	23.7	— 1	+ 4	55	
	27 .43	46	29.95	23.7	— 1	+ 4	49	
	24 .77	38	30.45	20.5	+ 7	+ 1	46	
	25 .88	41	30.45	20.5	+ 7	+ 0	48	
.5614 . .	39° 7′ 46″.49	1.522228	29.95	25.4	— 1	+ 6	33	1.522239 ± 1.0
	50 .81	41	29.95	25.4	— 1	+ 6	46	
	49 .12	36	29.95	25.5	— 1	+ 6	41	
	55 .16	55	30.35	18.7	+ 5	— 1	[59]	
	49 .48	37	30.35	18.8	+ 5	— 1	41	
	48 .72	35	30.35	18.9	+ 5	— 1	39	
	46 .88	29	30.45	21.0	+ 7	+ 1	37	
	47 .57	31	30.45	21.0	+ 7	+ 1	39	
E	39° 18′ 52″.13	1.524318	30.35	19.3	+ 5	— 1	22	1.524326 ± 1.5
	55 .51	29	30.35	19.4	+ 5	— 1	33	
	53 .14	22	30.35	19.4	+ 5	— 1	26	
	54 .50	26	30.35	19.4	+ 5	— 0	31	
	50 .47	13	30.45	21.5	+ 7	+ 1	21	
	50 .47	13	30.45	21.5	+ 7	+ 1	21	

TABLE II—Continued.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n	
F	39° 35′ 6″.47	1.527371	30.35	19.3	+5	−0	76	1.527379 ± 0.7
	8 .09	77	30.35	19.4	+5	−0	82	
	7 .26	74	30.35	19.5	+5	−0	79	
	5 .96	70	30.45	21.5	+7	+1	78	
	6 .86	72	30.45	21.5	+7	+1	80	
G	40° 5′ 47″.51	1.533118	29.95	24.6	−1	+1	18	1.533114 ± 1.1
	47 .33	17	29.95	24.7	−1	+1	17	
	43 .58	06	30.45	21.5	+7	+0	13	
	42 .79	03	30.45	21.5	+7	+0	10	
	42 .86	03	30.45	21.5	+7	+0	10	
.3956 . .	40° 33′ 32″.94	1.538290	30.30	14.0	+4	+1	95	1.538281 ± 2.2
	25 .42	66	30.30	14.15	+4	+1	71	
	27 .86	74	30.30	14.15	+4	+1	79	
	28 .15	75	30.45	21.8	+7	−0	82	
	27 .36	72	30.45	21.9	+7	−0	79	
	28 .98	77	30.45	22.0	+7	−1	83	

TABLE III.

Crown 1734. $\alpha = 59° 59' 2''.03 \pm 0''.36$.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n	
A	37° 55′ 22″.33	1.508718	29.87	25.5	−2	+8	24	1.508721 ± 1.3
	22 .58	19	29.87	25.6	−2	+8	25	
	20 .64	13	29.87	25.6	−2	+8	19	
	19 .31	09	30.45	18.1	+7	−3	13	
	20 .60	13	30.45	18.1	+7	−3	17	
	28 .49	38	30.42	6.0	+7	−20	25	
	27 .80	37	30.42	7.0	+7	−18	26	
B	38° 5′ 17″.16	1.510611	29.80	18.7	−3	−2	06	1.510606
	17 .09	11	29.80	18.9	−3	−1	07	
C	38° 10′ 16″.10	1.511561	30.45	20.3	+7	+0	68	1.511565 ± 1.5
	15 .24	58	30.45	20.5	+6	+1	65	
	14 .52	56	30.45	20.7	+7	+0	63	

TABLE III—Continued.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n	
D_2 . . .	38° 23′ 54″.02	1.514156	30.45	20.1	+7	0	63	1.514164 ± 1.1
	53 .95	56	30.45	20.1	+6	0	62	
	61 .08	78	30.42	8.5	+6	−12	72	
	58 .06	69	30.42	8.5	+6	−12	63	
	57 .66	67	30.42	8.5	+6	−12	61	
	57 .77	68	30.42	8.5	+6	−12	62	
.5614 . .	38° 30′ 49″.64	1.515472	29.87	25.7	−2	+6	76	1.515474 ± 0.6
	48 .13	68	29.87	25.8	−2	+6	72	
	48 .24	68	29.87	25.9	−2	+6	72	
	48 .16	68	29.87	25.9	−2	+6	72	
	47 .34	65	30.18	26.5	+2	+6	73	
	48 .81	69	30.18	26.5	+2	+6	77	
	49 .17	70	30.18	25.0	+2	+5	77	
E	38° 41′ 12″.20	1.517442	30.45	19.8	+7	−0	49	1.517440 ± 2.7
	12 .82	43	30.45	20.0	+6	+0	49	
	12 .64	43	30.18	25.0	+3	+4	50	
	9 .46	33	29.80	18.6	−3	−1	29	
	11 .26	38	29.80	18.6	−3	−1	34	
	9 .82	34	29.80	18.6	−3	−1	30	
F	38° 56′ 21″.19	1.520310	30.45	19.4	+7	−0	17	1.520317
	21 .55	11	30.45	19.5	+6	−0	17	
G	39° 24′ 48″.60	1.525679	29.87	26.0	−2	+2	79	1.525677
	47 .52	75	29.87	26.0	−2	+2	75	
.3956 . .	39° 50′ 24″.29	1.530485	29.87	25.4	−2	+0	83	1.530485 ± 0.5
	26 .12	90	29.87	25.4	−2	+0	88	
	24 .65	86	29.87	25.4	−2	+1	85	
	21 .48	76	30.45	18.5	+7	−0	83	
	23 .14	81	30.45	18.9	+6	−0	87	
	22 .99	81	30.42	6.0	+6	−1	86	
	22 .90	80	30.42	7.0	+6	−1	85	
	22 .90	81	30.42	7.0	+6	−1	86	

TABLE IV.

Flint 1588; $\alpha = 59° 59' 10''.73 \pm 0''.34$.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n	
A	48° 3′ 33″.89	1.618837	29.9	26.6	− 2	− 29	06	1.618812 ± 0.8
	35 .71	43	29.87	25.0	− 2	− 22	19	
	32 .20	33	29.87	25.0	− 2	− 22	09	
	21 .20	01	30.15	18.5	+ 2	+ 7	10	
	22 .54	06	30.15	18.4	+ 2	+ 7	15	
	22 .01	04	30.15	18.4	+ 2	+ 7	13	
	30 .92	29	30.20	24.5	+ 3	− 20	12	
	31 .34	31	30.20	25.0	+ 3	− 22	12	
	30 .80	29	30.20	25.0	+ 3	− 22	10	
B	48° 23′ 38″.26	1.622262	30.15	21.2	+ 2	− 6	58	1.622258
	37.90	61	30.15	21.2	+ 2	− 6	57	
C	48° 34′ 7″.54	1.624045	30.15	20.3	+ 2	− 2	45	1.624043 ± 0.8
	6 .96	43	30.15	20.3	+ 2	− 2	43	
	6 .20	41	30.15	20.3	+ 2	− 2	41	
D_2 . . .	49° 3′ 20″.12	1.628992	30.15	20.0	+ 2	0	94	1.628994
	20 .30	93	30.15	20.0	+ 2	0	95	
.5614 . .	49° 18′ 48″.49	1.631601	29.87	24.9	− 2	− 29	70	1.631578 ± 2.3
	40 .25	578	30.15	19.3	+ 2	+ 4	84	
	40 .97	80	30.15	19.3	+ 2	+ 4	86	
	39 .31	76	30.15	19.3	+ 2	+ 4	82	
	23 .11	30	30.3	14.0	+ 5	+ 35	70	
E	49° 41′ 49″.92	1.635468	30.15	19.0	+ 2	+ 6	76	1.635476
	50 .10	68	30.15	19.0	+ 2	+ 6	76	
F	50° 16′ 57″.18	1.641330	30.15	18.7	+ 2	+ 9	41	1.641340
	56 .50	28	30.15	18.7	+ 2	+ 9	39	
G	51° 25′ 51″.82	1.652709	29.87	24.5	− 2	− 37	70	1.652674 ± 1.0
	53 .54	14	29.87	24.6	− 2	− 38	74	
	53 .18	13	29.87	24.7	− 2	− 38	73	
	41 .16	680	30.15	18.4	+ 2	+ 13	[95]	
	20 .21	23	30.30	14.0	+ 5	+ 49	77	

TABLE IV—Continued.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n	
.3951 . .	52° 31′ 46″.70	1.663438	29.90	26.1	−2	−56	[80]	1.663358 ± 0.7
	34 .18	404	29.87	24.9	−2	−45	57	
	9 .59	338	30.15	18.4	+2	+15	55	
	10 .31	339	30.15	18.4	+2	+15	56	
	43 .93	430	30.30	27.7	+5	−71	64	
	41 .16	423	30.30	27.7	+5	−71	57	
	41 .56	424	30.30	27.7	+5	−71	58	
	41 .70	425	30.30	27.7	+5	−72	58	

The three values in these tables, which are included in brackets, cannot be reconciled to the other values of their corresponding quantities, and are rejected in deriving the mean. Ample justification for this course will be found in the section which treats of the probable accuracy of this work.

VI.

REDUCTIONS TO MEAN BAROMETER.

In any medium of refractive index μ', the observed index of refraction n of a medium having an index μ, in a vacuum, is given by the equation

$$n = \frac{\mu}{\mu'},$$

whence,

$$\frac{dn}{d\mu} = -\frac{\mu}{\mu'^2}.$$

If μ' refers to air, the law of refraction in gases gives

$$\mu' = k\,\mathrm{B} + 1$$

where k is a constant, and B is the barometric height, whence

$$\frac{d\mu'}{d\mathrm{B}} = k,$$

and the product of these two differential coefficients is

$$\frac{dn}{d\mathrm{B}} = -k\frac{\mu}{\mu'^2} = -n\frac{k}{\mu'^2} \text{ nearly.}$$

For the line D, when B is measured in inches,

$$k_{\mathrm{D}} = .982\,(10^{-5}),$$

and for a value of $B = 30$,

$$\mu'_D = 1.000295,$$

hence for this line and barometric height

$$\frac{dn_D}{dB} = -.981\,(10^{-5})\,n_D.$$

The values for this coefficient for the three varieties of glass in the order tabulated are:

No. 1720; $-.149\,(10^{-4})$
No. 1734; $-.148\,(10^{-4})$
No. 1588; $-.160\,(10^{-4})$

These, then, taken with the opposite sign and multiplied by the barometric height diminished by 30 inches, are the corrections to be applied to the observed values of n_D to reduce them to normal atmospheric pressure.

Within the limits of the observations, the greatest deviation from these values in B is 0.45; in $\frac{k}{\mu'^2}$ is .01; and in n is .0115,. 108, and .0211, respectively. We may, therefore, apply the corrections indicated as a constant throughout the spectrum.

VII.

REDUCTIONS TO MEAN TEMPERATURE.

In a paper cited above I have shown that the variations in the optical constants of glass from varying temperature may be considerable, and that the variation is largely dependent upon the wave-length. Within the errors of observation the law was found to be of the form

$$\frac{dn}{dT} = a + b\,\frac{1}{\lambda^2}.$$

In order to find the values of the constants for the three varieties of glass here discussed, equations of condition were formed of the form indicated by taking the individual values of n reduced to mean barometer, which were observed at different temperatures, or a value derived from the mean of n and T when several observations were made at nearly the same temperature. The values of Δn and ΔT employed are given in the following table, together with the normal equations derived from them:

$$\text{No. } 1734;\ \frac{\Delta n}{\Delta T} = -1.88 + 0.286\ \frac{1}{\lambda^2}$$

$$\text{No. } 1588;\ \frac{\Delta n}{\Delta T} = 2.53 + 1.05\ \frac{1}{\lambda^2}$$

The corrections to a mean temperature of 20° C., given under $\Delta_2 n$ in tables II, III, and IV, are calculated from these equations.

VIII.

ACCURACY OF ACCEPTED VALUES.

Some of the values of the various indices of refraction given above are derived from a small number of observations, closely accordant it is true, but not free from suspicion on that account. In others we have rejected certain values (three in all) which show a discrepancy much greater than we ought to expect from the probable error of a single observation. Finally, although the method of measurement described in Section III would seem to exclude all constant errors due to errors of graduation, a mistake in the Fraunhofer line selected, as for example in the line E, which, in the case of a crown glass prism of the small size used, is by far the most difficult line to set upon, does not seem wholly impossible. Thus, an independent test of accuracy is desirable. I have shown in a paper on Triple Objectives with complete color correction,* that the index of refraction of one kind of glass can be expressed as a trinomial function of that of another not too unlike it, with a degree of accuracy greater than that of direct measurement. Thus, if we express the index of refraction for No. 1734 as a function of that of No. 1720, and the mean difference between the observed values and those calculated from the formula connecting the two is not greater than we ought to expect from the probable errors attached to the individual values, we may be confident that the probable errors of our observations cannot be far wrong. By this method, also, we are certain to detect a large error in any accepted value, as well as to justify the rejection of the three discordant values of our tables.

The form of the function connecting refraction indices (n') of one kind with those (n) of another, was taken as

$$n' = a + bn + cn^2.$$

For convenience of computing, we may modify this equation to

$$(n' - n'_A) - (n - n_A) = \alpha + \beta\ (n - n_A) + \gamma\ (n - n_A)^2.$$

Making n' refer to the reduced indices of refraction of No. 1720, and n to those of

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No. 1734, we write nine equations of condition of the latter form: the resultant values of α, β, γ, deduced by least squares, are

$$\alpha = -0.18,$$
$$\beta = (10^{-2})\ 5.075,$$
$$\gamma = (10^{-7})\ 6.26.$$

By the substitution of these values in the equation above, we may compute values of $(n' - n'_{A}) - (n - n_{A})$ with which to compare the observed values.

$(n' - n'_{A}) - (n - n_{A})$		Δ
Obs.	Calc.	O − C
0.	− 0.2	+ 0.2
98.	98.0	0.0
155.	149.0	+ 6.0
291.	294.5	− 3.5
370.	370.9	− 0.9
491.	490.0	+ 1.0
668.	672.7	− 4.7
1042.	1040.6	+ 1.4
1401.	1400.7	+ 0.3
		Sum, − 0.2

If we regard these differences as due to errors of observation only, and there is no indication of the existence of a *systematic* difference, we can compute the probable value of a single difference from this table. If we call this probable difference Δ_0 we find, since there are three constants in the expression,

$$\Delta_0 = 0.674 \sqrt{\frac{\Sigma \Delta^2}{6}} = \pm 2.33.$$

But if we accept ± 1.7 as the probable error of each definitive value of both n and n', we ought to expect, according to well-known laws of probability,

$$\Delta = \pm 2.40.$$

The accordance of these two values is highly satisfactory, and, since in every case corresponding indices in the two glasses were measured by different lines on the circle of the spectrometer, it necessarily excludes all constant errors except such as might arise from *small* constant errors in the measured values of the angles of the prisms. Such errors, however, are hardly possible, since these angles were determined independently of the errors of graduation. This accordance also amply justifies our rejection of the discordant value in table II.

A similar test for the indices of No. 1588 cannot be obtained from these observations alone, since a trinomial expression is inadequate to express relations of the optical constants of two materials widely different. A formula with a larger number of arbitrary constants might be found to express these relations to any required degree of accuracy, but for the purpose in view such a formula would be much less useful. This becomes obvious when we reflect that we derive our confidence in the estimated values for the probable errors, from the agreement between the differences of the observed values and values calculated, with what the laws of probability would lead us to expect; but we can regard as fortuitous differences only a number equal to the whole number of arbitrary constants in the empirical formula. Thus, if the number of arbitrary constants were equal to the number of observed indices, the differences would all be zero, and no conclusion as to the probable errors could be drawn.

I have preferred, therefore, to express the values of the indices for No. 1588 as a function of those of a closely similar glass, flint 1237, the optical constants of which I have given in the paper cited above. In this glass

$$n_A = 1.615258,$$

which, with the numbers below, is all that is necessary to find all the values employed. The probable errors may be taken as ±2.8 as a mean. If n' refers to No. 1588, the constants of the formula

$$(n' - n'_A) - (n - n_A) = \alpha + \beta\,(n - n_A) + \gamma\,(n - n_A)^2$$

are found to be

$$\alpha = -\,2.08,$$
$$\beta = (10^{-3})\,1.992,$$
$$\gamma = -\,(10^{-8})\,2.165.$$

The observed values thus comparable with the calculated values here follow:

$(n' - n'_A) - (n - n_A)$		Δ
Obs.	Calc.	O − C
0.	− 2.1	+ 2.1
− 2.	+ 4.5	− 6.5
7.	7.7	− 0.7
19.	15.9	+ 3.1
23.	19.8	+ 3.2
29.	25.1	+ 3.9
30.	31.8	− 1.8
34.	40.5	− 6.5
47.	+ 43.7	+ 3.3
		Sum, − 0.1

From these values of $\varDelta$ we find the mean probable difference

$$\varDelta_0 = .674\sqrt{\frac{\Sigma\,\varDelta^2}{6}} = \pm 3.21.$$

But if ± 2.8 is the probable error of any one value of n, and ± 1.5 that of any one value of n', the mean difference which we ought to expect is ± 3.18. We may then regard the accuracy as estimated directly from the observations as worthy of great confidence.

IX.

SUMMARY.

We may here collect the results of the observations, attaching to each value of the observed index its probable error. In those cases where the probable error does not appear in tables II, III, and IV, we supply it by calculating from the mean probable error of a single observation, divided by the square root of the number of observations upon which our accepted value rests.

Crown No. 1720; $\alpha = 60^\circ\ 0'\ 16''.06 \pm 0''.42$; $\frac{\Delta n}{\Delta T} = -2.32 + 0.402\frac{1}{\lambda^2}$,

Crown No. 1734; $\alpha = 59^\circ\ 59'\ 2''.03 \pm 0''.36$; $\frac{\Delta n}{\Delta T} = -1.88 + 0.286\frac{1}{\lambda^2}$,

Flint No. 1588; $\alpha = 59^\circ\ 59'\ 10''.73 \pm 0''.34$; $\frac{\Delta n}{\Delta T} = +2.53 + 1.05\frac{1}{\lambda^2}$.

TABLE VI.

Line.	No. 1720.	No. 1734.	No. 1588.
A . . .	1.515116 ± 0.9	1.508721 ± 1.3	1.618812 ± 0.8
B . . .	1.517097 ± 1.0	1.510606 ± 2.2	1.622258 ± 1.8
C . . .	1.518115 ± 2.2	1.511565 ± 1.5	1.624043 ± 0.8
D_2 . . .	1.520850 ± 1.8	1.514164 ± 1.1	1.628994 ± 1.8
.5614 .	1.522239 ± 1.0	1.515474 ± 0.6	1.631578 ± 2.3
E . . .	1.524326 ± 1.5	1.517440 ± 2.7	1.635476 ± 1.8
F . . .	1.527379 ± 0.7	1.520316 ± 2.2	1.641340 ± 1.8
G . . .	1.533114 ± 1.1	1.525677 ± 2.2	1.652674 ± 1.0
.3956 .	1.538281 ± 2.2	1.530485 ± 0.5	1.663358 ± 0.7

DETERMINATION OF THE OPTICAL CONSTANTS OF CROWN GLASS No. 1937.

The density of this glass, of which the history is given in another place, was found to be 2.525, lying thus between that of the crown glass of the visual objective and the crown 1720 which was broken. It will be found that its optical constants are also intermediate.

As the plate of glass was not sufficiently thick for a useful prism, the necessary size was secured by cementing together two pieces, as in the case of the flint 1588 prism. The aperture of the prism as finished is 3.0 *cm.*

The same instrument and method as described above gave the following values for the refracting angle α:

$180^\circ - \alpha =$	$120 - 3' \, 43''.20$
	42.12
	43.68
$\alpha = 60^\circ \, 3' \, 43''.00$	

The determinations of the angles of refraction were made in precisely the same manner as those of the other glasses, consequently the table containing the results of observation needs no explanation. Since, however, no observations were made to determine the temperature coefficient of this material, all observations were made at about the same temperature, and, as nearly as convenient, at 20° C., the reduction then being assumed as the same as that for crown 1734, which it resembles closely.

TABLE VII.

Crown 1937. $\alpha = 60° \; 3' \; 43''.00$.

Line.	Δ	n_0	Bar.	T.	$\Delta_1 n$	$\Delta_2 n$	n
A	37° 58′ 5″.97	1.508353	29.9	21.5	— 1	+ 2	1.508353
	1 .95		29.9	21.5	— 1	+ 2	
	5 .40		30.0	20.0	0	0	
	6 .75		30.0	20.0	0	0	
	8 .43		30.0	20.0	0	0	
B	38° 8′ 12″.63	1.510284	29.9	22.0	— 1	+ 2	1.510284
	12 .28		29.9	22.0	— 1	+ 2	
	14 .44		29.9	21.0	— 1	+ 1	
	14 .36		29.9	21.0	— 1	+ 1	
	16 .85		29.9	21.0	— 1	+ 1	
C	38° 13′ 24″.66	1.511267	29.9	22.0	— 1	+ 2	1.511268
	24 .06		29.9	22.0	— 1	+ 2	
D_2	38° 27′ 27″.13	1.513933	30.0	21.0	0	+ 1	1.513934
	26 .44		30.0	21.0	0	+ 1	
	26 .53		30.0	21.0	0	+ 1	
.5614	38° 34′ 32″.63	1.515279	29.9	22.0	— 1	+ 2	1.515280
	33 .44		29.9	22.0	— 1	+ 2	
	31 .98		29.9	22.0	— 1	+ 2	
E	38° 45′ 4″.82	1.517274	29.9	21.0	— 1	+ 1	1.517276
	4 .97		30.0	22.0	0	+ 2	
	6 .64		30.0	22.0	0	+ 2	
	4 .16		30.0	22.0	0	+ 2	
F	39° 0′ 45″.82	1.520233	29.9	22.0	— 1	+ 1	1.520233
	44 .72		29.9	22.0	— 1	+ 1	
	44 .51		29.9	22.0	— 1	+ 1	
	45 .73		29.9	22.0	— 1	+ 1	
G	39° 30′ 1″.19	1.525741	29.9	21.5	— 1	0	1.525740
	2 .95		29.9	21.5	— 1	0	
.3951	39° 56′ 33″.15	1.530700	29.9	21.5	— 1	0	1.530700
	31 .55		30.0	22.0	0	0	
	28 .99		30.0	22.0	0	0	

The probable errors of the tabulated values of *n* for crown 1937 are about the same as those values for the other glasses; for, although the number of observations is less, the variation of temperature and barometric height during the observations was very small. A systematic comparison between the indices for this material and the quite similar crown 1734, shows a very satisfactory accordance, with the exception of the index for E, in which an error in the fifth place is indicated. I have already remarked on the difficulty of determining this index for crown glass with a moderate sized prism, but it is tolerably safe to assume that the larger 1937 prism is the less liable to error, and thus, if it ever be worth while, to correct the corresponding values for 1720 and 1734 by it.

C. S. HASTINGS.

Sheffield Scientific School, *New Haven*, 1889, April.

PART III.

INVESTIGATION OF THE GLASS SCALE "A"

OF THE

LICK OBSERVATORY MEASURING ENGINE.

By O. H. TITTMAN,

Assistant in the U. S. Coast and Geodetic Survey.

UNITED STATES COAST AND GEODETIC SURVEY,
OFFICE OF WEIGHTS AND MEASURES,
WASHINGTON, D. C., February 14, 1890.

Prof. T. C. MENDENHALL, *Superintendent U. S. C. and G. Survey, and of Weights and Measures:*

DEAR SIR: Herewith I submit the results of the comparison of the Lick Observatory glass scale A, forwarded to this office by Professor HOLDEN, and referred to in his letter of December 17, 1889.

Most of the comparisons were made by Mr. L. A. FISCHER, Adjuster, Weights and Measures office; some by Mr. F. H. PARSONS, Sub-Assistant; and some by myself, all the work having been done under my direction.

Yours respectfully,

O. H. TITTMANN,
Assistant C. and G. Survey.

REPORT ON THE COMPARISON OF THE LICK OBSERVATORY GLASS SCALE "A."

By O. H. Tittman.

The scale is ruled on a piece of glass about 8 inches long, 0.68 inch wide and 0.11 inch thick, which rests and slides on a brass frame having an inlaid silver scale, which is numbered.

The lines of the glass scale are about 0.02 inch apart and 0.13 inch long. They are of uniform length and unnumbered, and the parallel silver scale is designed to identify the individual divisions of the glass scale, but as the silver scale could not be used with our comparing apparatus, a paper scale suitably marked and temporarily fastened lengthwise on the glass served the same purpose.

In all the comparisons that line of the glass scale which is nearest the letter A, engraved on the underside of the glass, was called zero, and the other lines were numbered consecutively in the record from 0 to 300.

The observations were all made about midway between the top and bottom of the graduation. When "the scale" or "the length of the scale" is spoken of in this report, the space 0 to 300 is meant.

The absolute length of the scale was determined by comparison with the Brass Foot of 1880 (F_{1880}), the value of which, in terms of the British Imperial yard, is well known. The observations, made by myself, are as follows:

1890.		Temp. C_{Hy}.	Rev. Micr. 2.
February 1.	P. M.	19°.61	Scale $= \frac{1}{2} F_{1880} - 3.985$
February 3.	A. M.	16°.26	3.875
February 3.	P. M.	16°.67	3.922
February 4.	A. M.	17°.86	3.921
February 4.	M.	18°.32	3.978
	Means,	17°.74	Scale $= \frac{1}{2} F_{1880} - 3.936 \pm 95$

The coefficient of expansion of the scale may be assumed equal to .000008 for 1° C_{Hy}, and that of F_{1880} is .000018 for 1° C_{Hy}.

The value of 1 revolution of micrometer No. 2 = 0.001225 inch. Reducing to 16°.67 C_{Hy}, we have

$$\text{Scale} = \tfrac{1}{2}\,F_{1880} - 3.883 \pm 0.0095 \text{ rev.},$$

but at 16°.67 C_{Hy},

$$\tfrac{1}{2}\,F = 5.99991 \text{ inch};$$

hence, at 16°.67 C_{Hy},

$$\text{Scale} = 5.99515 \pm 1.1.$$

Since the probable error of this comparison appears to be very small, it is permissible to ascribe a larger one to the absolute value of the scale; in accordance with general experience, we may write therefore at 16°.67,

$$\text{Scale} = 5.99515 \pm 5.$$

Having determined the absolute length of the scale, the corrections to the 50, 100, 150, 200, 250, and 300 division-marks were determined in terms of the scale itself by HANSEN'S method elaborated by Dr. BROCH, late Director of the International Bureau of Weights and Measures.

The comparisons were made on SAXTON'S dividing-machine by Mr. L. A. FISCHER, Adjuster, Weights and Measures office.

Five sets of comparisons were made on different days. Each value given in the following abstract is the mean result of five comparisons.

The method consists in comparing the separate spaces, indicated under that heading in the abstract, with an auxiliary space, approximately equal to the space compared. The auxiliary intervals are symbolized by the letter λ, and the given numerical unit of the observed differences is the one ten-thousandth of an inch.

RESULTS OF THE COMPARISON OF THE SCALE
WITHIN ITSELF AT 16°.8 C.

Space.	Space.
0 to 50 = $\lambda_6 - 12.2$	0 to 150 = $\lambda_4 - 25.1$
50 to 100 = $\lambda_6 - 16.3$	50 to 200 = $\lambda_4 - 29.0$
100 to 150 = $\lambda_6 - 17.3$	100 to 250 = $\lambda_4 - 28.8$
150 to 200 = $\lambda_6 - 16.6$	150 to 300 = $\lambda_4 - 21.2$
200 to 250 = $\lambda_6 - 16.1$	
250 to 300 = $\lambda_6 - 9.9$	0 to 200 = $\lambda_3 - 42.6$
	50 to 250 = $\lambda_3 - 45.9$
0 to 100 = $\lambda_5 - 17.3$	100 to 300 = $\lambda_3 - 39.7$
50 to 150 = $\lambda_5 - 22.4$	
100 to 200 = $\lambda_5 - 23.2$	0 to 250 = $\lambda_2 - 53.4$
150 to 250 = $\lambda_5 - 22.1$	50 to 300 = $\lambda_2 - 51.4$
200 to 300 = $\lambda_5 - 14.9$	

Adjusting these observations, we obtain the following corrections and their probable errors, the numerical unit being as before, one ten-thousandth of an inch:

Divisions on Scale.	Corrections.
0	00.00 ±
50	— 2.42 ± 0.09
100	— 0.98 0.08
150	+ 1.67 0.08
200	+ 3.61 0.08
250	+ 4.86 0.09
300	0.00

Substituting the absolute value of the scale and its probable error as previously found, we obtain the absolute values of the spaces with their probable errors as given in the appended final table.

For the purpose of finding the values of the spaces from zero to the 10 division-mark on the scale and to multiples of 10, a centimeter stop of the SAXTON dividing-machine was utilized. By means of it the 0 to 20, 20 to 40, 40 to 60, 60 to 80, and 80 to 100 spaces were compared with each other four times.

The correction to the 100 division-mark, previously found, was assumed to have determined the position of the mark with absolute correctness on the scale, as far as the adjustment of the subdivisions is concerned. The space 0 to 100 having been divided into five parts by the measurement of the 20 division-spaces above described, the position of the 20, 40, 60, and 80 marks on the scale became known. The spaces 100 to 200 and 200 to 300 were each similarly divided into five parts, and thus all the even multiples of 10 were determined and entered in the table.

The position of the 10 division-mark was determined by comparing the spaces 10 to 30 and 30 to 50 with a 20 division-space before determined. By subtracting the values thus found from the 50 division-mark, the positions of the 10 and 30 marks became known. The spaces 50 to 150 and 150 to 250 were then each divided into five parts, as described for the even multiples of 10, and thus the uneven multiples of 10 become known.

Having thus determined the corrections for 30 spaces of 10 divisions each, it remained to establish the inter-relation of the single division-spaces. This was done by putting two sets of parallel threads, a little less than 0.02 inch apart, into the focus of the ocular of micrometer B of the BLAIR comparator (magnifying power, 50–60; value of 1 division = .00001329 inch) and by measuring the spaces. Putting the distance between the sets of parallel threads $= x$, the space on the scale when viewed through the microscope appeared = to $x+a$ number of divisions measured. The object in fixing the threads a little less than a scale space apart was to avoid contrary signs in the record, and thus to insure accuracy and to simplify the calculation.

Each space was measured first by Mr. L. A. FISCHER, and subsequently and on different days by Mr. F. H. PARSONS. As the result of the measures, equations were established for each 10 division-space, of the following form:

$$10\,x+a=n_{10}-n_0,$$
$$10\,x+b=n_{20}-n_{10},$$
$$\text{etc.,}\qquad\text{etc.,}$$

where x is the distance between the sets of parallel threads, assumed constant during the time occupied in measuring 10 spaces, and a, b, etc., the observed excess of the spaces over $10\,x$, n the division-marks on the scale with their index numbers. For the value of a single space

$$n_1-n_0=\frac{n_{10}-n_0}{10}+z_1-\frac{a}{10},$$
$$n_{11}-n_{10}=\frac{n_{20}-n_{10}}{10}+z_{11}-\frac{b}{10},$$
$$\text{etc.,}\qquad\text{etc.,}$$

where z is the excess of the space over x.

The values of the spaces thus obtained have been entered in the table which gives the distance from zero to each division-mark on the scale, at 16°.67 Centigrade hydrogen scale.

TABLE OF SCALE A OF THE L. O. MEASURING ENGINE.

Scale.	Inch.	Scale.	Inch.	Scale.	Inch.	Scale.	Inch.	Scale.	Inch.
0	0.00000	41	0.81952	81	1.61881	121	2.41801	161	3.21715
1	.01995	42	.83948	82	.63878	122	.43800	162	.23713
2	.03994	43	.85946	83	.65878	123	.45790	163	.25711
3	.05997	44	.87947	84	.67877	124	.47791	164	.27713
4	.07997	45	.89947	85	.69879	125	.49788	165	.29713
5	.09998	46	.91947	86	.71875	126	.51784	166	.31712
6	.11994	47	.93948	87	.73876	127	.53782	167	.33705
7	.13992	48	.95946	88	.75872	128	.55780	168	.35705
8	.15991	49	.97944	89	.77867	129	.57778	169	.37704
9	.17989	50	0.99943	90	1.79867	130	2.59777	170	3.39704
10	0.19988		±1	91	1.81867	131	2.61775	171	3.41699
11	0.21991	51	1.01941	92	.83862	132	.63774	172	.43702
12	.23995	52	.03938	93	.85863	133	.65774	173	.45701
13	.25999	53	.05934	94	.87859	134	.67772	174	.47701
14	.27996	54	.07928	95	.89861	135	.69767	175	.49695
15	.29990	55	.09926	96	.91858	136	.71763	176	.51694
16	.31988	56	.11924	97	.93854	137	.73758	177	.53692
17	.33987	57	.13918	98	.95854	138	.75757	178	.55691
18	.35984	58	.15919	99	.97851	139	.77757	179	.57693
19	.37981	59	.17915	100	1.99848	140	2.79756	180	3.59689
20	0.39978	60	1.19916		±3	141	2.81756	181	3.61690
21	0.41980	61	1.21918	101	2.01847	142	.83754	182	.63688
22	.43978	62	.23918	102	.03846	143	.85752	183	.65690
23	.45977	63	.25917	103	.05844	144	.87750	184	.67689
24	.47979	64	.27912	104	.07845	145	.89745	185	.69683
25	.49976	65	.29912	105	.09845	146	.91745	186	.71682
26	.51974	66	.31911	106	.11843	147	.93741	187	.73677
27	.53973	67	.33910	107	.13839	148	.95739	188	.75673
28	.55975	68	.35908	108	.15838	149	.97739	189	.77669
29	.57973	69	.37904	109	.17835	150	2.99741	190	3.79668
30	0.59969	70	1.39905	110	2.19836		±3	191	3.81665
31	0.61968	71	1.41903	111	2.21831	151	3.01741	192	.83664
32	.63964	72	.43898	112	.23825	152	.03741	193	.85658
33	.65962	73	.45899	113	.25827	153	.05741	194	.87656
34	.67959	74	.47895	114	.27823	154	.07737	195	.89654
35	.69955	75	.49888	115	.29818	155	.09732	196	.91652
36	.71958	76	.51888	116	.31813	156	.11728	197	.93647
37	.73956	77	.53887	117	.33812	157	.13724	198	.95644
38	.75955	78	.55888	118	.35813	158	.15725	199	.97645
39	.77956	79	.57887	119	.37810	159	.17724	200	3.99641
40	0.79951	80	1.59882	120	2.39805	160	3.19723		±4

TABLE OF SCALE A OF THE L. O. MEASURING ENGINE—Continued.

Scale.	Inch.	Scale.	Inch.	Scale.	Inch.	Scale.	Inch.	Scale.	Inch.
201	4.01636	221	4.41603	241	4.81564	261	5.21531	281	5.61515
202	.03638	222	.43600	242	.83564	262	.23530	282	.63517
203	.05641	223	.45596	243	.85558	263	.25528	283	.65515
204	.07641	224	.47596	244	.87562	264	.27526	284	.67514
205	.09643	225	.49593	245	.89558	265	.29523	285	.69521
206	.11640	226	.51593	246	.91553	266	.31519	286	.71519
207	.13639	227	.53587	247	.93551	267	.33516	287	.73520
208	.15641	228	.55591	248	.95549	268	.35515	288	.75519
209	.17637	229	.57585	249	.97552	269	.37512	289	.77514
210	4.19639	230	4.59581	250	4.99547	270	5.39513	290	5.79514
211	4.21632	231	4.61583		±5	271	5.41512	291	5.81516
212	.23628	232	.63580	251	5.01545	272	.43514	292	.83517
213	.25623	233	.65576	252	.03543	273	.45510	293	.85517
214	.27619	234	.67570	253	.05542	274	.47506	294	.87523
215	.29619	235	.69571	254	.07541	275	.49506	295	.89524
216	.31617	236	.71568	255	.09540	276	.51507	296	.91520
217	.33615	237	.73568	256	.11537	277	.53504	297	.93517
218	.35617	238	.75568	257	.13534	278	.55509	298	.95518
219	.37610	239	.77568	258	.15531	279	.57510	299	.97516
220	4.39606	240	4.79570	259	.17532	280	5.59512	300	5.99515
				260	5.19532				±5

The table gives the distance from 0 division to any division-mark on the scale at 16°.67 Centigrade.

Let S_0 be any such distance at 16°.8 C., and S_t be the same distance at t degrees.

$$S_t = S_0\,(1 + 0.000008\,(t - 16^\circ.8))$$

PART IV.

SPECTROSCOPIC OBSERVATIONS OF NEBULÆ,

MADE AT MOUNT HAMILTON, CALIFORNIA,

WITH THE

THIRTY-SIX INCH REFRACTOR OF THE LICK OBSERVATORY.

BY PROFESSOR JAMES E. KEELER, Sc.D.,
Director of the Allegheny Observatory.

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SPECTROSCOPIC OBSERVATIONS OF NEBULÆ.

By James E. Keeler.

I.

INTRODUCTION, AND REVIEW OF PREVIOUS OBSERVATIONS.*

In No. 11 of the *Publications of the Astronomical Society of the Pacific*, I gave a preliminary account of spectroscopic observations of a number of planetary nebulæ, in which it was shown that some of these bodies have a considerable motion in the line of sight. The present paper contains a full account of these observations, and of many others which have since been made, with examples to show the degree of confidence to which they are entitled. Numerical values, which are believed to be very near the truth, have been assigned to the motions of a number of the brighter nebulæ, and the wave-lengths of the principal nebular lines have been determined with as much accuracy as possible by means of the best modern optical appliances.

Owing largely to the researches of Professor Lockyer, the spectral analogies which are presented by the various classes of celestial bodies have, in the last four years, received more attention than astronomers had formerly given them. The principal lines in the spectra of the nebulæ may probably be regarded as the signature of the earliest stage of stellar development, and although their full significance is at present unknown to us, they must always be of the highest importance in the study of celestial spectrum analysis. They have been identified, perhaps somewhat hastily, with lines in the spectra of "temporary" stars, and they may possibly appear periodically in the spectra of well-known variables, a point which may well be made the subject of future investigation. As it is however impossible, or at least scarcely practicable, to bring the spectrum of a nebula into juxtaposition with that of any other celestial body under observation, it is important to know the exact positions of the nebular lines with reference to the spectra of the common metals, in order that the comparison may be conveniently made, and its error due, as nearly as possible, solely to the comparison itself.

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* In this section, wave-lengths are given, as originally determined, in Ångström's scale. For reasons which will be given in the proper place, I have adopted Rowland's system of wave-lengths in reducing my own observations.

In this section of my paper I desire to give a brief history of previous observations of the spectra of nebulæ, so far as they relate to the positions of the principal lines. While it is possible that some observations may have been overlooked, I believe that all the more important papers on this subject are mentioned in the following review.

The bright-line character of nebular spectra was discovered by Dr. HUGGINS* in 1864, and the approximate positions of the principal lines were determined by him at the same time. The principal line appeared to coincide with the brightest air line, a coarse double, the mean position of which is λ 5003. The second line was a little less refrangible than the strong barium line at λ 4934. The third and faintest line seen at the time of discovery was coincident with the H_β line of hydrogen. As this position of the third nebular line has since been abundantly confirmed, and the presence of hydrogen in the nebulæ is now undoubted, no further observations of the third line need be mentioned.

In 1865, SECCHI† observed the *Orion* nebula with a spectroscope of small dispersive power, and made a rough sketch of the spectrum, in which the positions of the lines are mere eye-estimates.

The second paper‡ by Dr. HUGGINS on the spectrum of the nebulæ gives an account of observations made with apparatus somewhat more powerful than that used in 1864, two prisms of 60° each being employed. The principal line still appeared to coincide with the double nitrogen line, and the comparison was stated to be trustworthy within the limits of about the breadth of the double line D; that is, within about 6 tenth-meters.

Dr. HUGGINS at that time considered that the principal nebular line was probably due to nitrogen, a view which was strengthened by the observation that when the nitrogen spectrum was sufficiently dimmed, the bright line at λ 5003 alone remained, and it could no longer be recognized as double.

The middle, or second line, could not be identified with any terrestrial line. It was observed to be by a very slight amount less refrangible than the line of oxygen at λ 4953, and in a rather larger degree less refrangible than the barium line at λ 4934.

In 1868 Lieutenant HERSCHEL§ made some measures of the position of the chief line in the spectra of a number of nebulæ, mainly in the southern hemisphere, but with apparatus so deficient in optical power that the numerical results were less satisfactory than the previous ones of HUGGINS. The range of the different values obtained for the wave-length of the principal line is as much as 100 tenth-meters.

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* *Phil. Trans.*, 1864.

† *Comptes Rendus*, vol. 60, p. 543.

‡ *Phil. Trans.*, 1868, p. 541.

§ *Proc. Roy. Soc.*, vol. 16, p. 451. These observations were reduced by D'ARREST, who published the results in 1872.

Spectroscopic observations of nebulæ were made at Harvard College Observatory in 1868,[*] the positions of the principal lines being only roughly determined.

In 1871, Professor VOGEL[†] observed a number of different nebulæ with the refractor at Bothkamp, and determined the positions of the brightest lines in their spectra. The chief line was observed to coincide with the double nitrogen line; its wave-length by measurement was 5005.3, the different values obtained having a range of about 6 tenth-meters. The wave-length of the second line was found to be about 4960. I have examined these measures to see if there is any evidence in them of the small displacements which were subsequently detected at the Lick Observatory, but it is evident that the whole range of these small differences of position is less than the probable error of the Bothkamp measurements. Professor VOGEL detected the second line in the spectrum of the ring nebula in *Lyra.*

In 1872, Dr. HUGGINS,[‡] employing more powerful apparatus than in 1868, compared the principal line in the spectrum of the nebula of *Orion* with the double nitrogen line, and found that the nebular line apparently coincided with the lower component of the nitrogen double. According to this observation, the wave-length of the nebular line would be λ 5005. Notwithstanding the want of coincidence of the nebular line with the middle of the nitrogen double, Dr. HUGGINS was still disposed to regard the nebular line as due to nitrogen, and ascribed its displacement to recession of the nebula from the Sun. Measures of the second line placed it at λ 4957, near a strong iron line, and its origin was regarded as unknown. A fourth line in the spectrum of the nebula was coincident with the H_γ line of hydrogen. All the lines were very fine and sharp.

In a paper communicated to the Royal Society in 1874,[§] Dr. HUGGINS gives the results of further observations of the spectrum of the nebulæ. The chief line was apparently coincident with the middle of the less refrangible line of the double line of nitrogen. A line in the spectrum of lead was found to fall almost exactly upon the lower component of the nitrogen double, and as it is fine and sharp, while the nitrogen lines are broad and hazy, it proved to be more suitable as a fiducial line of comparison. The chief nebular line was very slightly less refrangible than the lead line, and hence its wave-length was slightly greater than λ 5004.5.

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[*] *Annals of the Harvard College Observatory*, vol. 13, part I.

[†] *Bothkamp Beobachtungen*, Leipzig, 1872.

[‡] *Proc. Roy. Soc.*, vol. 20, p. 383.

[§] *Proc. Roy. Soc.*, vol. 22.

Comparisons of the lead line with the chief line in the spectra of a number of different nebulæ were made in order to ascertain whether any of the nebulæ were moving in the line of sight, with the result that "in no instance was any change of relative position of the nebular line and the lead line detected." The conclusion drawn from these comparisons was that none of the nebulæ could have a motion greater than 25 miles per second, the earth's motion at the time being included.

In this paper Dr. HUGGINS seems to have abandoned his former views as to the origin of the chief nebular line, although no express statement to this effect is made. It was obviously improbable that all the different nebulæ observed should have a motion of recession such as to bring the chief line, if due to nitrogen, into coincidence with the less refrangible of the two lines in the spectrum of terrestrial nitrogen.

Measures of the positions of the three brightest lines in the spectra of a number of nebulæ were made by Professor BREDICHIN[*] in 1875, but the optical power of the apparatus being small, the measures are not very accordant. Professor BREDICHIN concluded, however, from these observations, that in all the nebulæ the corresponding lines are of identical origin.

In 1880 Dr. COPELAND[†] made some measures of the principal lines in the spectra of the nebulæ *N. G. C. 7026* and *N. G. C. 7027*. The mean of the results for the chief line was λ 5012; for the second line, λ 4963. A single prism spectroscope was used, and the wave-lengths are necessarily rough approximations.

Measures of the brightest lines in the spectrum of the *Orion* nebula were made in 1886 and 1887 by Dr. COPELAND[‡] at Dun Echt, giving for the chief line a wave-length of λ 5004, and for the second line, λ 4958. The range of values for the chief line is 4 tenth-meters. A faint line was detected at the place of the D_3, or "helium," line of the solar spectrum.

So far, no explanation of the origin of the two brightest nebular lines had been attempted since the abandonment of the original belief of Dr. HUGGINS that the chief line was due to nitrogen. Dr. HUGGINS considered the nebulæ to be masses of glowing gas, containing hydrogen and some unknown substance or substances, to which the other two principal nebular lines were due. In 1887, however, Professor LOCKYER, in elaborating his well-known "Meteoritic Hypothesis," suggested that the chief nebular line is due to magnesium rendered luminous by collisions among the swarm of meteorites which he considers to constitute the nebulæ. According to Professor LOCKYER, the magnesium fluting at λ 5006.4 is far brighter at a low temperature (that of the Bunsen burner) than almost any other spectral line or fluting of any element whatever. The chief nebular line he regarded as the "remnant" of this fluting, the shading on the more refrangible side, and the other maxima of the fluting, being invisible on account of their faintness.

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[*] *Spectre des Nébuleuses*, *Annales de l'Observatoire de Moscou*, vol. II, p. 60.

[†] *Copernicus*, vol. I, p. 2.

[‡] *Monthly Notices*, *R. A. S.*, vol. 48, p. 360.

This explanation of Professor LOCKYER'S gave a new impulse to the study of the nebular lines. Professors LIVEING and DEWAR[*] stated that the fluting at λ 5006.3 is due to an oxide of magnesium, and that it is scarcely visible in the presence of hydrogen, which is admitted to be one of the constituents of the nebulæ. They also disputed the correctness of Mr. LOCKYER'S statement that the fluting at λ 5006.3 appears at a lower temperature than the characteristic triplet which corresponds with the chief lines of the *b* group in the solar spectrum. Mr. ALBERT TAYLOR,[†] observing with a 12-inch refractor, found the appearance of the spectrum of the *Orion* nebula to be consistent with Professor LOCKYER'S explanation, although his conclusions as to the origin of the lines are scarcely borne out by his measurements. The wave-length of the chief line was 5001; that of the second line, 4953.

In 1889, Dr. and Mrs. HUGGINS[‡] compared the chief nebular line with the magnesium fluting, using in one instance a dispersion nearly equal to that of eight prisms of 60°. With this dispersion, which was much greater than any that had hitherto been used, the nebular line appeared to them to be more refrangible than the edge of the magnesium fluting, and in the position which they had formerly assigned to it. The authors quote various observations, which indicate that the chief line does not have the appearance of a fluting, but is fine and sharp, like the hydrogen lines. A list of the lines observed and photographed in the spectrum of the *Orion* nebula is given, the wave-lengths of the first and second lines being, respectively, λ 5004.6 to λ 5004.8, and λ 4957.0.

A large part of the important paper by Dr. and Mrs. HUGGINS is devoted to a consideration of the photographic spectrum of the nebula of *Orion*, with the conclusion that neither eye observations nor photographs afford any evidence that magnesium is present in the nebulæ.

In a paper[§] communicated to the Royal Society in the early part of 1890, Professor LOCKYER reviews at lĕngth all previous observations on the position of the chief nebular line, giving the values obtained by different observers, and showing that on the basis of these measurements, he was justified in regarding the chief line as coincident with the lower edge of the magnesium fluting. He then gives an account of some of his own observations, in which a siderostat was employed to reflect the light of the nebula of *Orion* into a fixed horizontal telescope of 10 inches aperture. The spectroscope had three prisms of 45° refracting angle and one of 60°. With this apparatus, which was adjusted by the aid of the Moon and stars, Professor LOCKYER found that the coincidence of the chief nebular line and the edge of the magnesium fluting appeared to be perfect.

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[*] *Proc. Roy. Soc.*, vol. 44, pp. 242 and 245.

[†] *Monthly Notices, R. A. S.*, vol. 49 (1889), p. 124.

[‡] *Proc. Roy. Soc.*, vol. 46.

[§] *Proc. Roy. Soc.*, vol. 48. Incorporated in "The Meteoritic Hypothesis," London, 1890.

Observations were also made on the aspect of the chief nebular line, and on a number of occasions the line is described as having a fringe on the more refrangible side, thus resembling a fluting. Observations of other observers who had recorded a similar appearance of the line are also given. On the strength of the evidence collected in this paper, Professor LOCKYER concluded that the chief nebular line is a remnant of the magnesium fluting at λ 5006.4, and re-asserted the correctness of his views as to the constitution of the nebulæ.

The limits within which Professor LOCKYER considered his observations to be trustworthy are not directly stated in this paper, although the fact that he was able to distinguish between the lower of the two nitrogen lines and the edge of the magnesium fluting, which are separated by an interval of about 2 tenth-meters, is some indication of the degree of precision which was obtained. The observations themselves give some information as to the inferior limit. On both November 27th and February 5th the coincidence of the nebular line and the edge of the magnesium fluting appeared to be perfect. This could not, however, have actually been the case, since, on account of the effect of the earth's orbital motion, the nebular line at the time of the latter observation was 0.46 tenth-meter less refrangible than at the time of the former. An interval of this magnitude was therefore imperceptible.

On account of the publication of this paper by Professor LOCKYER, Dr. and Mrs. HUGGINS* were induced to repeat their observations, and they obtained the same results as before; namely, that the nebular line is more refrangible than the edge of the magnesium fluting, and that it is sharply defined on both sides. The wave-length assigned to the chief line as observed was λ 5005.0, or, corrected for the orbital motion of the earth at the time, λ 5004.75. The observations were independently confirmed by Professor LIVEING with the same apparatus. The testimony of several observers in favor of the sharpness of the chief line is also given.

It will be seen from the observations and papers so far quoted, that the limits within which the position of the chief nebular line was in dispute had been narrowed to the place of the lead line used by Dr. HUGGINS, on the more refrangible side, and to that of the magnesium fluting on the less refrangible side, the interval between the lines being no more than 2 tenth-meters.

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* *Proc. Roy. Soc.*, vol. 48.

The first spectroscopic observations of nebulæ at the Lick Observatory were made a short time before the last-mentioned paper was published, at the request of Dr. HUGGINS, who asked that the position of the chief nebular line should be determined with reference to the edge of the magnesium fluting, with the aid of the large spectroscope of the 36-inch equatorial, and also that the character of the nebular lines should be examined.

A few comparisons were made of the chief line in the spectrum of the *Orion* nebula and the spectrum of lead, but as the observations were made under unfavorable circumstances and were much interfered with by clouds, I did not consider them as entitled to much confidence. The appearance of the lines was, however, carefully studied. The observations on the position of the principal line being indecisive, I therefore, at Dr. HUGGINS' request, examined the spectra of the nebulæ *G. C. 4234* (Σ 5) and *G. C. 4373*, employing for the purpose a diffraction grating of 14438 lines to the inch. In both of these nebulæ the brightest line fell well above the lower edge of the magnesium fluting, with which it could not be made to coincide by any maladjustment of the comparison spark, the observations thus confirming the opinion of Dr. HUGGINS in regard to the non-coincidence of the nebular line and the terminal line of the magnesium fluting. There was, however, such an appreciable difference in the positions of the brightest line in the two nebulæ that it was evident that one or both nebulæ had a considerable motion in the line of sight.

Many nebulæ were then observed, and in ten the brightest line was found to be sufficiently bright for an accurate determination of its position. As these observations are incorporated in the present memoir, it is not necessary to give the individual results, which were printed in a paper "On the Motions of the Planetary Nebulæ in the Line of Sight."[*] The wave-length of the chief nebular line, from the mean of the ten nebulæ observed, was λ 5005.68 on ÅNGSTRÖM'S scale, a result which is subject to some uncertainty, arising from the motions of the different nebulæ and the effect of the proper motion of the solar system.

In the winter of 1890–91, I determined the position of the chief line in the spectrum of the nebula of *Orion*, and at the same time measured the displacement of the third line by comparisons with terrestrial hydrogen.[†] According to these observations the *Orion* nebula was receding from the sun at the rate of 10.7 miles per second, and the normal position of the chief line was λ 5005.93.

In this brief sketch of the history of previous observations on the position of the chief nebular line, it has been possible to give no more than a mere outline of the results which are contained in the papers referred to in the text. For a complete statement of these results, and of other important observations on the spectra of the nebulæ, the original papers must be consulted.

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[*] *Publications of the Astronomical Society of the Pacific*, No. 11.

[†] *Proc. Roy. Soc.*, vol. 49, p. 399.

The only other observations on the motions of the nebulæ, besides those by Dr. HUGGINS already mentioned, that have come to my knowledge, are those made at Greenwich by Mr. MAUNDER.* The results for the nebula of *Orion* vary from 51 miles of approach to 11 miles of recession, and are evidently lacking in the precision which is requisite in such measurements. From the observations of 1884, Mr. MAUNDER concluded that the nebula of *Orion* has little, if any, motion in the line of sight.

In my paper on the motions of the planetary nebulæ in the line of sight, I said, in reference to the negative result of previous investigations: "The conclusion that the nebulæ have no motion relatively to the solar system would appear on *a priori* grounds to be improbable. The stars, which in general are found to have considerable motions in space, are, according to modern views, evolved from preëxisting nebulæ by a process of contraction or condensation, and any motion of translation possessed by the star must have been inherent in the original nebula, since in no way could such a motion have been acquired by any internal action during the process of condensation. The *absence* of motion in the nebulæ would, in fact, if proved by observation, be a remarkable circumstance, which would need to be explained."† It will be shown in the present paper that the planetary nebulæ are moving in space with velocities of the same order as those of the stars.

As the measures made at the Lick Observatory are of a high degree of precision, notwithstanding the faintness of the objects observed, I have thought it desirable to give a somewhat complete description of the apparatus which was used, and examples in detail of each class of observations. The observations which have been selected for this purpose are neither those which exhibit an unusual accordance nor those which are unusually discrepant, but such as seemed to be fairly representative of the average work.

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* *Greenwich Spectroscopic and Photographic Results*, 1884 and 1887.

† *Publications of the Astronomical Society of the Pacific*, No. 11, p. 267.

II.

DESCRIPTION OF THE APPARATUS.

The star spectroscope used in connection with the 36-inch equatorial was made by Mr. J. A. BRASHEAR, of Allegheny, Pa., mainly from drawings furnished by myself. It is of admirable workmanship throughout, and I am indebted to Mr. BRASHEAR for various useful additions to the original design of the instrument, as well as for modifications which insure greater strength and rigidity of its different parts.

The spectroscope, which weighs nearly 130 pounds, is supported by two heavy brass rods (or tubes, as they are hollow) 3 inches in diameter and 6 feet long. The upper ends of these rods for 2½ feet of their length are inserted in triple clamps on opposite sides of a large sleeve or collar which surrounds the tail-piece of the telescope tube. The collar turns on ball bearings, and is provided with position circle, clamp, and slow motion screws. The rods when in place are parallel to each other and to the axis of the telescope, are 23¼ inches apart between centers, and extend 2 feet 3 inches beyond the focal plane of the objective. The frame of the spectroscope is secured to the lower ends of these rods by four clamps, two on each side, which are so arranged that the frame cannot be strained when they are tightened. When the spectroscope is to be mounted, the rods are first inserted and secured by circular nuts on their upper ends and by their clamps. The spectroscope is then laid upon the rods and allowed to slide down until it reaches stops placed for the purpose on their lower ends, and its clamps are tightened. Balancing weights equivalent to the weight of the spectroscope are removed from the lower end of the telescope tube to complete the operation, which requires the work of two persons for about twenty minutes.

The case in which the collimator slides is supported by the main frame of the spectroscope, and is provided with adjusting-screws, by which the collimator can be directed to the center of the object-glass of the great telescope. The collimator can be moved in its slide, by a rack and pinion attachment, through a range of 100 millimeters, or about four inches, its position being indicated on a millimeter scale by a pointer outside the case. As the stops on the lower ends of the large brass rods always bring the spectroscope into the same position with respect to the focal plane of the objective, the readings of the collimator scale which bring the slit into the proper position for different parts of the spectrum are always the same, variations due to changes of temperature not being considered. These readings have been determined from a consideration of the color curve of the objective* and are given in the following table:

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* *Publications of the Astronomical Society of the Pacific*, No. 9.

READING OF COLLIMATOR SCALE FOR DIFFERENT FOCI OF THE 36-INCH EQUATORIAL.

Line or Wave-Length.	Reading of Scale.
B	76.6
C	82.7
D	88.0
Minimum Focus	88.5
b	85.2
λ 5005	81.5
F	76.6
Hγ	39.8
Hδ	6.5

The effect of changes of temperature on these readings has not yet been ascertained.

The collimator objective has a focal length of 20 inches and a clear aperture of 1½ inches. The lenses are thin, made of Jena glass, and cemented with Canada balsam to diminish the loss of light by internal reflection.

The slit has a number of important attachments which are worthy of notice. It is mounted in a tube provided with a rack and pinion for focusing, a millimeter scale, and a clamp. The jaws are moved equally from the center by a right and left-handed screw, one turn of which widens the slit by $\frac{1}{40}$ inch. The slit is also variable in length, two small slides moving lengthwise from the center just within the jaws, and operated by a knob, being the means by which the change is effected. A diagonal eye-piece is used for viewing the slit from behind and for setting the instrument accurately on the object which it is desired to study. When this adjustment is effected, the eye-piece is slightly withdrawn to allow the light to pass. This eye-piece is a great convenience—indeed, a necessity—when such a large telescope is employed, as the telescope cannot be pointed with sufficient accuracy by means of its finders.

Just without the slit is the totally-reflecting 60° prism of the comparison apparatus. It is mounted on a slide, and can be moved smoothly lengthwise along the slit by a milled head within reach of the observer. When moved inward as far as it will go, it extends a little beyond the middle point of the slit.

All this apparatus is protected by a large, thin tube, which screws on to the upper end of the collimator, and which also serves to hold the tubes for cylindrical lenses. Large apertures allow access to the slit, and the passage of light from the comparison spark.

At the lower part of the spectroscope frame, one on each side, are the pivots of the strong cross-piece into which the observing telescope is screwed. On the left (in the usual position of the instrument) is the graduated circle, 12 inches in diameter, divided on the edge, on silver, to 10′, and read by two opposite verniers to 10″. The circle is fixed, and the verniers are carried by the movable arm. The pivot on the right is pierced centrally by a conical hole, in which turns the spindle of the grating-table. This is a circular plate 4½ inches in diameter, to which the grating-mount is attached. The outer end of the spindle carries a knob for rotating the grating-table, and a small circle, provided with a tangent-screw, which can be thrown out of gear.

The ROWLAND grating has a ruled surface $2\frac{1}{16}$ by $3\frac{3}{16}$ inches, with 14438 lines to the inch. On one side the higher orders of spectra are very brilliant. All necessary adjustments are provided.

There are three prisms: one of 30°, one of 60°, and one compound prism of about 3½ times the dispersion of the latter. Each prism is cemented to a circular plate, or table, in which are three small foot-screws for adjusting. Two long clamping-screws hold the prism-table firmly against the grating-table (which is of the same size), and when the prism is once adjusted by its foot-screws, which are made to turn with some difficulty as a guard against accidental disturbance, the prism can be removed and replaced at any time without requiring readjustment. The grating and prisms can thus be interchanged very readily. When a prism is used, it is first set carefully to minimum deviation for any part of the spectrum, by means of the tangent-screw on the spindle of the grating-table. A small clamp-screw is then turned, connecting the spindle with the tail-piece of a minimum deviation contrivance, and the tangent-screw is thrown out of gear. The prism is then automatically kept in the position of minimum deviation for all parts of the spectrum. If the minimum deviation clamp is not tightened, the prism will remain in a fixed position; or if the tangent-screw is also thrown out of gear, the prism can be rotated freely by hand.

There are two observing telescopes: one of the same focal length as the collimator, the other only about half as long. The short telescope, which is much the more convenient for ordinary purposes, was used in all the observations described in the present paper. Its objective is of 1½ inches aperture and 10 inches focal length, and, like the collimator lens, is made of Jena glass. The tube, although so short, is 2½ inches in diameter, and it is consequently very rigid. The draw-tube at the eye end has a rack and pinion motion for focusing, a clamp, and a graduated scale, exactly like the same attachments on the slit-tube.

The micrometer carries a fine wire, a coarse wire, and a pointer. Its head is divided on silver into 100 parts, and one revolution is equal to 3′ 10″.8. A number of eye-pieces are provided, only two of which were used in observations of nebulæ.

They are both achromatic, one magnifying 7.3 and the other 13.3 diameters. The higher power was generally used.

A small incandescent electric lamp, in a lantern on the upper side of the observing telescope, serves to illuminate both the upper vernier of the graduated circle and the micrometer wires. For this purpose an opening is cut in the side of the lantern, directly opposite the shade of the upper vernier, and this opening is closed by a small slide, which is pushed aside when it is desired to read the circle. From one end of the lantern a small tube runs parallel to the telescope to the end of the micrometer-box, into which the light is reflected by a small prism. The strength of the illumination is regulated by slightly rotating the short piece of tube in which this prism is mounted. A disc containing colored glasses on the end of the micrometer-box allows the color of the light to be varied so as to approximately match that of any part of the spectrum.

An elaborate reversion attachment, the reversing prism of which is rotated by a very fine micrometer-screw acting on the end of a long arm, can be inserted between the observing telescope and its support. This apparatus answers well for some purposes, such as the measurement of the rotation of the Sun by displacement of lines in the spectra of its opposite limbs, but like other devices of the kind, it has the disadvantages of causing great loss of light, and of giving the inferior definition which arises from the use of but half of an object-glass. No trial of it has therefore been made in measurements of lines in the spectrum of the nebulæ.

The comparison apparatus is clamped to one of the rods which support the spectroscope. It has forceps for holding metallic electrodes, and a holder for spectrum tubes, with all necessary adjustments. An image of the spark (or tube) is formed on the slit by a lens having a somewhat greater angular aperture than the collimator.

A medium-sized Ruhmkorff coil, capable of giving a 3-inch spark, is used in connection with the comparison apparatus. The coil, a battery of four large cells, and a Leyden jar for strengthening the spark, are carried by a truck mounted on rubber casters, and these are so arranged that the adjusting-screws of the coil are within easy reach of the observer when the floor is at a convenient height for observation.

The Lick Observatory spectroscope, like the spectrometer used in laboratory work, has all its parts open to inspection, and not, as is frequently the case with star spectroscopes, inclosed in protecting shields or covers. This construction has both advantages and disadvantages. Among the former must be reckoned ease of access to the essential parts, and facility in making changes for adapting the instrument to different classes of observations; among the latter are exposure to dust, and liability to accidental disturbance of the adjustments. In my opinion the plan adopted in the Lick Observatory spectroscope is preferable for large instruments, and the inclosed form for small ones. The instrument which I have described has proved to be very convenient for all the purposes considered in its construction. When not in use on the telescope, it is kept on a truck made for the purpose, fitted with drawer, etc., for holding accessories, and can then be used for laboratory experiments.

III.

EXPERIMENTS ON INSTRUMENTAL ERRORS.

In such delicate observations as measurement of the motions of celestial bodies in the line of sight, it is of the greatest importance to ascertain the magnitude of errors which may arise through imperfect adjustment of the instrument and other causes, as such errors may very easily exceed in amount the small displacements which it is desired to measure. The apparatus described in the preceding section has been carefully studied in this respect. Most of the experiments were made when observations were first begun for determining the position of the chief nebular line, others during the course of the work, while some of the best tests of the apparatus are afforded by the observations themselves. For convenience, they may all be considered together.

The proper arrangement of the comparison apparatus is one of the most important subjects for consideration. It is essential that corresponding lines in the direct and reflected spectra of the same substance shall be in exact coincidence. In the Lick Observatory spectroscope this condition is insured by causing the two sets of rays to pursue identically the same path in the instrument. The arrangement of the totally-reflecting prism which has already been described, is intended to be free from the objections which have been made to the usual construction in which the comparison prism is employed. When the spectroscope is used on the 36-inch telescope, the effective aperture of the collimator is 1.06 inches, and the actual aperture is reduced to 1.06 inches by a stop, so that the emergent beam is just permitted to pass. In observations of the *Orion* nebula a slightly elliptical aperture was used, in order to permit the use of a greater length of slit without loss of light. An image of the comparison spark, intentionally somewhat out of focus (in order that the light shall completely fill the slightly widened slit), is formed on the slit by a lens which has a larger angular aperture than the collimator, and hence the collimator aperture is also completely filled with light from the comparison spark. I may point out that the uniform illumination of the collimator lens is not generally possible with a 45° reflecting prism, as some of the convergent rays from the image lens are intercepted by the slit-plate. The 60° reflecting prism allows the whole cone of rays to pass without obstruction.

This arrangement of the comparison apparatus seems to me preferable to the one sometimes employed, in which a narrow beam from the spark is made to fall centrally upon the collimating lens in the direction of its optical axis. In the arrangement I have described, the exact coincidence of the two spectra is *a priori* probable, and if it is observed to exist within the limits of error of estimation, the presumption is that the coincidence is perfect. With the other arrangement, apparent coincidence can be effected only by trial and adjustment, and any observation subsequently made is affected by both the error of the observation itself and that of the previous adjustment.

When a grating is used, the spectral lines are straight, and one source of embarrassment attending the use of prisms is avoided.

A method which experience at Potsdam has shown to be unexceptionable is to place a spectrum tube at right angles to the slit, and at some distance from it. In this case the collimator lens is not uniformly illuminated, but, as the spectral line is formed by light coming from those parts of the lens which have the greatest influence in determining its exact position, there is no appreciable error of displacement. This method is not, however, applicable to metallic spectra, as the spark between the electrodes is very short.

In the Lick Observatory spectroscope, the spectrum tube is placed parallel to the slit, and care must be taken, not only that the collimator aperture is filled with light, but that the spectral lines are images of the slit, and not of the capillary bore of the tube. It is easy to determine which is the case by observing the appearance of the lines while the slit is widened and narrowed. If the lines are bounded by the jaws of the slit, they will vary in width equally on both sides.

In a note printed in the *Publications of the Astronomical Society of the Pacific*, No. 8, I have called attention to the great advantage attending the use of objectives made from certain varieties of Jena glass. Hardly any change of focus is necessary, in the instrument I have used, throughout the entire range of the visible spectrum. In differential measurements, where both lines have very nearly the same wave-length, the chromatic aberration of the objectives is of no importance, but for general purposes the use of Jena glass in spectroscopes cannot be too strongly recommended.

It is hardly necessary to say that these remarks do not apply to one or two special kinds of Jena glass, which are hygroscopic. A very perfect color correction can be obtained with glasses free from this defect.

On beginning work which required the use of the comparison spectrum, the following experiments were made on the adjustment of the apparatus and the effect of various instrumental errors:

1. The collimator was adjusted so that its optical axis was coincident with the optical axis of the great telescope.

2. The micrometer wires were placed in the principal focal plane of the object-glass of the observing telescope, by observations of stars and of distant mountains. The reading of the eye-tube for this position of the wires was found to be 12.3 (millimeter) divisions.

3. The observing telescope having been placed in position on the spectroscope, and the 36-inch refractor directed to the Sun, a wave-length of about 5000 in the third spectrum of the grating was brought into the field. The eye-piece was first carefully focused on the micrometer wires in this colored light, and the slit was then focused until the solar lines were perfectly sharp, when it was securely clamped. Micrometer wires and slit were then assumed to be in the principal focal planes of their respective object-glasses.

To test this adjustment the solar spectrum was observed with the compound prism. When the observing telescope was set to a greater angle than that of minimum deviation and the spectrum was brought into the field by rotating the prism, the solar lines near λ 5000 were perfectly sharp in both possible positions of the refracting edge, a proof that the rays falling on the prism were parallel, and that the micrometer wires were in the proper position.

4. Lead electrodes having been placed in the comparison apparatus, the coarse micrometer wire was set on the lead line at λ 5005.6* in the fourth spectrum of the grating. The width of the slit was such as to make the bright lead line a very little wider than the micrometer wire, an adjustment which allowed a very minute displacement of the line to be detected. By slightly rocking the electrode-holder the rays from the spark were thrown alternately on opposite sides of the collimator objective, but the displacement of the line was barely perceptible.

Assuming the perfect adjustment of the slit and micrometer wire, and leaving out of consideration the effect of diffraction due to the use of only a part of the objectives, it is evident that this experiment is simply a test for spherical aberration, which had already been found by the ordinary methods to be perfectly corrected.

5. A sodium flame was placed close in front of the slit, and magnesium electrodes, containing sodium as an impurity, were placed in the comparison apparatus. The D lines in both spectra coincided exactly in all the different orders of the grating.

6. The same experiment was repeated for the *b* lines, magnesium ribbon being burned in front of the slit. The coincidence was exact. On bringing the magnesium fluting at λ 5007.5 into the field, the edge of the fluting in the direct

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* In the remainder of this paper, wave-lengths will be given on ROWLAND'S scale. See Part V.

spectrum extended a little beyond the same edge in the reflected one, toward the less refrangible end of the spectrum. This effect seemed to me to be due to the much greater brilliancy of the direct spectrum. When the light from the burning ribbon was dim, the coincidence became nearly perfect.

7. The spectroscope, mounted on its truck, was directed to a heliostat (improvised out of some common mirrors and the 6-inch equatorial), and a beam of sunlight was thrown into the collimator. An image lens was placed in the course of the rays, in order to obtain a divergent beam and fill the aperture of the collimator objective with light. The solar D lines were compared with the sodium lines from the comparison apparatus, and the coincidence was found to be perfect.

The spectroscope truck was then placed obliquely, so that the beam of sunlight coming through the slit fell on only half of the collimator objective, and a very slight displacement of the solar lines was noticed.

Next, the eye-tube carrying the micrometer was withdrawn three (millimeter) divisions, and the definition of the solar lines was restored by focusing the slit. The displacement of the D lines became quite perceptible, although it was but a small fraction of the interval between the lines. The experiment was repeated with the wires three divisions inside the proper focus, and with the same result.

The conclusion drawn from these experiments was that no appreciable errors were to be feared from such small derangements of the adjustments as were likely to occur in practice. Further, since the only effect of flexure in the main telescope tube, or its connections with the spectroscope, is to produce a slight inclination of the collimator axis to the axis of the great telescope, no appreciable error can be caused by flexure, the inclination of the collimator produced in this way being inconsiderable, compared with the inclination given to it in the experiments. Flexure of the spectroscope itself has no influence on the observations described in this paper, as all the important measures are differential.

Notwithstanding the conclusion just stated, special experiments bearing on the subject of flexure were made on a number of occasions, and an account of them is given, with some others, below.

8. On July 17, 1890, the position of the chief nebular line in the spectrum of the nebula *G. C. 4390* was determined, with reference to the lead line at λ 5005.6, with the spectroscope slit in a parallel of declination, and again with the slit in a meridian, to ascertain the possible effect of flexure. The position of the nebular line was the same in both cases.

Measures in the spectrum of *Arcturus*, which were begun about this time, as a check, gave a much smaller motion of approach than that which had been obtained at Greenwich; and as the chief nebular line also appeared to have a lower position in the spectrum than it should have had, according to the best determinations at that time published, further experiments were made on the subject of constant errors.

9. On July 24, 1890, the interval between the lead line at λ 5005.6 and the chief line in the spectrum of Σ 6 (*G. C. 4390*) was measured with the usual arrangement of apparatus. The grating was then removed and reversed, and the observing telescope turned to the opposite side of the collimator. On remeasuring the place of the nebular line, a slightly different result was obtained, but as the same experiment was repeated on a number of different nights and no change in the position of the nebular line was detected, the slight discrepancy in the first result was considered to be accidental.

10. The grating was removed and the compound prism substituted. *Arcturus* and *G. C. 4390* were observed, the results being in agreement with those obtained with the grating. The D lines in the spectrum of *Arcturus*, and the chief line in the spectrum of the nebula, were in the positions formerly obtained, as nearly as could be judged with the much lower dispersion of the prism. An error of one fifth the interval between the D lines could not have been committed.

On turning to the nebula *G. C. 4373*, the difference of position of the chief line, as compared with the chief line in the spectrum of *G. C. 4390*, was quite perceptible with the prism, the nebular line apparently coinciding with the lead line at λ 5005.6. The slight interval between these lines, which was subsequently measured with the grating, was imperceptible with the prism.

From these experiments it was apparent that both grating and prism gave the same result, and that any possible source of error need not be looked for beyond the collimator.

11. For the sake of completeness, observations for flexure were made on the *Orion* nebula when it was nearly on the meridian. The distance (Δλ) between the lead line at λ 5005.6 and the chief nebular line was measured in four positions of the spectroscope. Each measure was made by setting twice on the nebular line and twice on the lead line, alternately. The following results were obtained:

(*a*) Position circle at 30°. Slit in parallel of declination. Observing telescope above and north. Δλ = 2.09 tenth-meters.

(*b*) Position circle at 120°. Slit in meridian. Observing telescope east. Δλ = 2.15 tenth-meters.

(*c*) Position circle at 210°. Slit in parallel. Observing telescope below and south. Δλ = 2.03 tenth-meters.

(*d*) Position circle at 300°. Slit in meridian. Observing telescope west. Δλ = 2.01 tenth-meters.

(*e*) Position circle at 30°, as at first. Δλ = 2.10 tenth-meters.

The differences of these results are within the limits of error of the measurements, considering the inconvenience of observing in some positions of the instrument, and hence there is no evidence of error due to flexure.

The observations which have been described in this section show that, with the instrument carefully adjusted, no appreciable constant errors can affect the measurements. With proper precautions, personal errors can be nearly eliminated. It may be noted that the continual shifting of the lines in the spectra of the heavenly bodies, due to the earth's orbital motion, serves admirably as a guard against personal bias of the observer. The lines are never twice in the same place (certain limiting conditions excepted), and unless the observer takes the trouble to estimate beforehand the effect of the earth's motion, he cannot tell how his micrometer wire should be placed in order to obtain results consistent with former ones. Almost all the observations of planetary nebulæ described in the present paper were made without any recollection of previous results.

The final test is the consistency of the results which have been obtained for all the different classes of objects.

IV.

METHOD OF OBSERVATION.

In all measurements of the position of spectral lines the ROWLAND grating was used on the large spectroscope, and the observing telescope was always set to a reading of 140°. The reading on the slit, with the telescopes in line, was 0°, so that the axes of the observing telescope and collimator were inclined to each other at an angle of 40°. The part of the spectrum to be examined was then brought into the field by rotating the grating. When a wave-length of 5006 in the fourth spectrum was in the center of the field, the normal to the grating was on the other side of the collimator, and inclined at an angle of about 17¼° to the axis of the latter.

The nebular lines were observed in either the third or the fourth spectrum. The third spectrum was somewhat the brighter, but experience showed that the error of an observation, expressed in wave-lengths, was usually less in the fourth spectrum. Of the two eye-pieces, the higher power (13.3 diameters) was generally found to be the more satisfactory, except on unusually faint nebulæ. The dispersion when the fourth spectrum was employed was about equal to that of twenty-four prisms of 60°. The theoretical resolving power of the instrument in the fourth spectrum was 64, equivalent to that of twenty-four prisms each 1.05 inches on the base. There is no doubt that the practical efficiency of an instrument for determining the positions of such faint lines as those of the nebulæ is not determined solely by the resolving power. Of two instruments equal in this respect, that having the higher dispersion would be the more advantageous. In the third spectrum the dispersion was that of fourteen prisms.

When a small object, such as a planetary nebula, is observed with the Lick Observatory spectroscope, it is first centered in the slit by the slow motions of the main telescope, with the aid of the diagonal eye-piece, which has already been described. The slit is then shortened until its length is just equal to the diameter of the nebula, and its width is reduced to suit the requirements of observation. The slit is then evidently completely filled with light from the nebula. After its image (*i. e.*, the nebular line) has been bisected with the micrometer wire, the comparison prism is moved into place, and the image of the nebula is replaced by the image of the comparison spark. It is evident that the rays of light from both sources enter the same part of the slit, traverse the same path in the spectroscope, and fall upon the same part of the micrometer wire. It was shown in the preceding section how completely all constant errors are avoided by this arrangement. If desired, the two spectra can be compared directly, the comparison prism being then moved so as not to completely cover the open part of the slit. The position of the nebular line is determined by setting the micrometer wire alternately on this line and on the line of comparison, the latter being of course selected so as to make the distance to be measured as small as possible.

In the earlier observations at Mount Hamilton, the position of the chief nebular line was determined with reference to both the lower edge of the magnesium-flame band and the lead line just above it at λ 5005.6, the nebular line usually falling between these limits. As the lead line offers a much better mark for the micrometer, the use of the magnesium fluting as a reference line was afterwards abandoned, but not until it had been shown that the accuracy of the observations was in no way impaired by so doing. For comparisons with the second nebular line, the double iron line at λ 4957.6 was used.

With the high dispersion of the fourth spectrum of the grating, only the brightest nebular line, when in the proper position for observation, was in the field, although the first and second lines could be seen together by setting the telescope on the point midway between them. The lower of the two nitrogen lines and the edge of the magnesium fluting were separated by a considerable interval (nearly a whole revolution of the micrometer), and a small fraction of the interval was easily measurable.

In most nebulæ the principal line with this dispersion was faint, but in some, notably the *Orion* nebula, *G. C. 4390*, and *N. G. C. 7027*, it was remarkably bright and sharp, and could be observed with almost as great accuracy as the metallic line of the comparison spectrum. With a very narrow and full-length slit, the bright lines in the spectrum of the nebula of *Orion* had exactly the appearance of illuminated micrometer wires in a dark field. Although I have not actually made the comparison, it seems to me quite probable that the grating may give a brighter spectrum than a train of prisms having an equal resolving power. How far the brightness of the spectrum depends upon the qualities of the particular grating I have used, I am not able to say, but it is probable that any of the gratings made by ROWLAND, which are so ruled as to give bright spectra of the higher orders, would answer the purpose equally well. The 36-inch telescope affords no advantage in the observation of such large, diffuse objects as the nebula of *Orion*, and a smaller telescope, with thinner objective, would give brighter spectra. On the other hand, it gives a decided advantage in the observation of small planetary nebulæ, for the visibility of small, faint objects depends very much upon their size, as well as upon their intrinsic brilliancy, and the size of the image in the focus of the main telescope determines the length of the lines observed in the spectroscope. The intrinsic brilliancy of the third line in the spectrum of *G. C. 4390* is greater than that of the same line in the spectrum of the nebula of *Orion*, but in the case of *G. C. 4390*, comparisons with the $H\beta$ line of hydrogen were much the more difficult when a very narrow slit was used.

I may remark here that the descriptions of nebulæ in the *New General Catalogue* of DREYER are of but little service in the selection of objects for such observations as these. In some of the nebulæ marked "very bright," the lines could not be seen at all with the grating, while among the nebulæ described as simply "bright," are some of the brightest in the sky. This is doubtless because the observations in the catalogue were made with telescopes of very different sizes, and are therefore not comparable, and because the catalogue "brightness" is usually an estimate vaguely compounded of intrinsic brightness and size. A faint nebula, if large, is generally recorded as bright, and a bright but small nebula as faint. The distinction between quantity of light and intrinsic brightness becomes more obvious the greater the size of the telescope employed, and the revision of the description of brightness in the notes of the catalogue would be a real service to observers with large instruments, although it would certainly be a far from easy task.

In measuring the spectra of the nebulæ, the slit was narrowed so that the bright lines of the nebula and the comparison spark were just the width of the coarse micrometer wire (0.35 tenth-meters). The settings were then made by occulting the bright lines by the wire. A very faint, diffuse light in the field was found to be an advantage during this operation, even when the nebular line was dim, as the diffuse light did not seem to affect the visibility of the line, and the eye could be more easily kept in the proper position for observation. The faint illumination was readily obtained by placing a lantern where it would shine on the floor in front of the grating. On a few occasions bright wires were used in a dark field.

Before making the micrometer measures, a direct comparison of the nebular and reference lines was usually made by bringing both lines into the field at the same time. In some nebulæ, however, the chief line was too faint to be seen alongside of the rather bright continuous spectrum of the lead or magnesium spark.

In order to eliminate personal errors in setting the micrometer, the observer stood alternately on opposite sides of the instrument, thus having the upper end of the spectrum alternately on his right and on his left hand. In some cases when a star was observed at a considerable hour-angle, and it was impossible to follow out this plan on account of the position of the instrument, the effect of personal error is noticeable. It seemed to be smaller for a nebular than for a stellar line.

No cylindrical lens was used in observing stars. The D lines in a stellar spectrum looked like small black dots on a narrow line of light.

The electric control described in *Publications of the Astronomical Society of the Pacific*, No. 6, was sometimes used, but not often, as the equatorial driving-clock ran sufficiently well without it.

The value of a micrometer revolution in different parts of the spectrum was determined by measuring the interval between solar lines, and checked in some instances by computing the value from the theory of the grating. The results are exhibited in tabular form below:

VALUE OF ONE REVOLUTION OF MICROMETER.

Line.	Third Spectrum.		Fourth Spectrum.	
	Tenth-Meters.	Miles per Second.	Tenth-Meters.	Miles per Second.
D	3.29	104.3	. . . .	. . . .
b	3.60	. . . .	2.10	. . . .
Chief Neb. Line . . .	3.71	. . . .	2.21	. . . .
Second Neb. Line . .	3.73	. . . .	2.24	. . . .
F	3.75	144.0	2.28	87.6

Unless the sky was cloudy in the daytime, the spectroscope was always adjusted on the Sun. The full aperture of the telescope was used, and the spectroscope was protected from the great heat by a sheet-iron screen with a small aperture over the slit.

The interval between the first and second lines in the spectra of a number of different nebulæ was measured with the graduated circle, as it was too great for the range of the micrometer. In making the measures, the micrometer head was first set to about $2^{r}.60$. The coarse wire was then in the center of the field, and the reading on the slit, when the telescope was brought into line with the collimator, was very nearly 0°. The circle was then set to 140°, making the angle between the axes of the telescopes about 40°, and the grating was turned until the brightest nebular line in the fourth spectrum fell upon the coarse micrometer wire. The telescope was directed alternately upon the first and second nebular lines by turning the tangent-screw, the circle being read for each setting, until as many measures were obtained as was desirable. The electric illumination, controlled by a switch in the hand of the observer, was used only in bringing the micrometer wire approximately on the nebular line, the final setting being made by occulting the line in a dark field. The reflected image of the slit from the surface of the grating was then observed, and finally the slit itself, the grating being removed (or turned edgewise). These observations give all the data for computing, by the formulæ for the diffraction grating, the wave-length of the brightest line and the difference of wave-length of the first and second lines, the absolute wave-length to be regarded as merely approximate, and useful only as a check.

The formula for the reflecting grating is

$$n\lambda = \sigma (\sin \psi - \sin \varphi),$$

in which φ = angle between the normal to the grating and the incident ray.
ψ = angle between the normal to the grating and the diffracted ray (φ and ψ being measured in opposite directions from the normal).
λ = wave-length.
n = order of spectrum.
σ = distance between centers of lines of the grating.

For two rays measured in the same position of the grating,

$$n(\lambda_1 - \lambda_2) = \sigma (\sin \psi_1 - \sin \psi_2).$$

An approximate value of ψ_1 or ψ_2 is required for the determination of $\lambda_1 - \lambda_2$, and a precise value of $\psi_1 - \psi_2$.

V.

POSITIONS OF COMPARISON LINES.

In my preliminary work on the nebulæ, all positions of lines were referred to ÅNGSTRÖM'S scale, for the reason that it has been used by all previous investigators of nebular spectra, and their results would therefore be more readily comparable with my own. As the work progressed, however, it became evident that the errors of ÅNGSTRÖM'S scale, and of the best available measures of the reference lines which I used, were much greater than the errors of my differential measurements of lines in the spectra of the nebulæ.

I have lately, by the kindness of Professor ROWLAND, obtained some very accurate positions of the reference lines which were most subject to uncertainty.

They were determined by Mr. LEWIS E. JEWELL, Professor ROWLAND'S assistant, with the great concave grating spectroscope of the Johns Hopkins University. The measures in this paper have been reduced to these lines as standards, and all positions are given on ROWLAND'S scale.

The comparison lines which I have used in the differential measures are the line of lead at λ 5005.6, the edge of the magnesium (or magnesium oxide) fluting at λ 5007.5, the double line of iron at λ 4957.6, the two yellow sodium lines, and the hydrogen line Hβ.

The advantage of the lead line as a fiducial line of comparison, in measures of the chief nebular line, was pointed out by Dr. HUGGINS* in 1874. It is fine and sharp, and an excellent mark for the micrometer.

The wave-length of this line is, according to WATTS (THALEN'S measures), 5004.6 on ÅNGSTRÖM'S scale.

The value adopted by HUGGINS in his later investigations is 5004.5.

LOCKYER, in connection with his work on the nebula of *Orion*, re-determined the place of the lead line, and made the wave-length 5005.0.

Its place on ROWLAND'S scale, according to the measures by Mr. JEWELL, is λ 5005.634.

The place on ÅNGSTRÖM'S scale of the lower edge of the magnesium fluting, according to a number of different authorities, is given below:

WATTS	λ 5006.5
HUGGINS	5006.5
LIVEING and DEWAR . . .	5006.4
LOCKYER	5006.5

My own results accord well with those given above, but all are evidently affected with a constant error of the reference scale. A few rough measures which I made for determining the positions of the secondary maxima of the fluting agreed well with LOCKYER'S values.

In observations for deciding one of the questions which are considered in this paper—whether the chief nebular line is in any way related to the magnesium fluting—the absolute wave-lengths of the reference lines are less important than their relative positions. I therefore measured the interval between the lead line and the edge of the fluting, using the same apparatus as in the observations of nebulæ. The slit-width was such as to make the lead line just the width of the coarse micrometer wire (0.35 tenth-meter).

In determining the position of the edge of a fluting certain precautions are necessary, as the position depends upon the width of the slit. If the distance between the lead line and the fluting could be measured with a slit-width vanishingly small, the true interval would be obtained. On giving the slit a practicable width, the position of the center of the line is unchanged, but the edge of the fluting is shifted toward the red by half the width of the line.

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* *Proc. Roy. Soc.*, No. 151, 1874.

In measuring the interval between the line and the fluting, the line was observed by occulting it with the micrometer wire, the observation thus referring to its center, but the fluting was observed by bringing its extreme edge and the *lower* edge of the micrometer wire into coincidence, the center of the wire falling therefore upon the place which the edge of the fluting would have with an infinitely narrow slit. The comparisons of the nebular line and the magnesium fluting were also made in this way. Other measures of the interval between the lead line and the edge of fluting were made with the fine micrometer wire and as narrow a slit as could be used. With a faint light the measurement is a difficult one, more difficult than the measurement of the place of a nebular line.

The interval obtained as a result of my own measures was 1.86 tenth-meters. It was somewhat greater when the brilliant light from burning magnesium was used, as the illumination of the terminal line of the fluting is not equal on both sides, and a small apparent displacement is caused by irradiation; but with the comparatively feeble light of the comparison spark used in the observation of nebulæ, the distance obtained was that given above. This would make the wave-length on ROWLAND'S scale 5007.494. The value communicated by Professor ROWLAND, and adopted in my reductions, is 5007.473.

The position of the iron doublet is given by SCHEINER in *Die Spectralanalyse der Gestirne*, pp. 380 and 405. The wave-lengths of the two components, in the Potsdam system, are 4957.53 and 4957.90. The wave-lengths on ROWLAND'S scale, from the Baltimore measures, are 4957.482 and 4957.786.

With the slit-width used in observations of nebulæ, the iron line could not be recognized as double. The observations refer to the center of the pair, or to λ 4957.634.

The other reference lines are well-known lines in the solar spectrum, and no comment on their positions is required.

It is remarkable that the lines in the spectra of the common metals are not yet (with the exception of iron and some few others) determined with sufficient accuracy to serve as reference points for measurements in the spectra of such faint objects as the nebulæ. Dr. SCHEINER, in his *Spectralanalyse der Gestirne*, has called attention to the imperfect determinations of the principal metallic lines, and Dr. HUGGINS has lately referred to the same subject, in his address as President of the British Association, at Cardiff. The difficulty will doubtless be remedied in the near future.

VI.

EXAMPLES OF OBSERVATIONS.

It is not necessary or desirable to give in full all the spectroscopic measures which were made in connection with the study of the nebulæ. A sufficient number of examples for different objects is given below, to show the details of the observations. Except that the notes are occasionally somewhat expanded, so as to be intelligible to the general reader, the observations are given exactly as they are recorded in my note books.

The micrometer wire was set alternately on the line in the spectrum of the heavenly body, and on the line of the comparison spectrum. With the arrangement of apparatus which has already been described, the micrometer readings increase with the wave-length. Hence, if N is the micrometer reading for the line of the nebula or other heavenly body, C the corresponding reading for the comparison line, λ_C the wave-length of the comparison line, and R the value of one revolution of the micrometer in tenth-meters, the wave-length of the nebular line is

$$\lambda_N = \lambda_C + (N - C) R.$$

The direction of the displacement of the nebular or stellar line was usually noted by a direct comparison, to prevent mistakes.

The reading of the index of the micrometer head was sometimes changed, so that the reading with a given wire in the center of the field was not always the same.

The Sun. May 15, 1891.

Measurement of interval between the D lines. Grating, 3d spectrum. Fine wire.

These measures are made in order to show the accuracy with which the micrometer wire can be set on the sharpest possible lines for comparison with the observations of stars and nebulæ.

D_2	D_1	Diff.
$21^r.194$	$23^r.025$	$-1^r.831$
.226	.026	.800
.219	.019	.800
.205	.019	.814
.208	.019	.811
.197	.024	.827
.197	.018	.821
.195	.015	.820
.210	.020	.810
.219	.019	.800
		$-1^r.813$

Taking for the interval between the D lines 5.955 tenth-meters, the value of one revolution of the micrometer is 3.29 tenth-meters, the same value as that given in the table in Section IV.

The Moon. October 23, 1890.

Comparison of the D_1 line with the Na_1 line of sodium. Grating, 3d spectrum.

The fine micrometer wire is used, and the observer is alternately east and west of the instrument. Moon near the meridian, and all circumstances favorable. Observations equal to the best.

By direct comparison the coincidence of the D and sodium lines appears to be perfect.

D_1	Na_1	Diff.
$13^{r}.480$	$13^{r}.472$	$+ 0^{r}.008$
.479	.470	+ .009
.463	.472	− .009
.490	.475	+ .015
.440	.460	− .020
.467	.482	− .015
.468	.462	+ .006
.410	.443	− .033
.490	.468	+ .022
.442	.410	+ .032

$+ 0^{r}.002 = + 0.2$ miles per second.

Venus. April 3, 1891.

Comparison of the D_1 line with the Na_1 line of sodium. Grating, 3d spectrum.

Planet near the meridian; measures apparently good. The fine wire is used. By direct comparison the lines in the spectrum of the planet are perceptibly displaced toward the red.

D_1	Na_1	Diff.
$21^{r}.170$	$21^{r}.107$	$+ 0^{r}.063$
.156	.104	.052
.180	.104	.076
.165	.110	.055
.165	.113	.052
.166	.106	.060
.182	.109	.073
.188	.116	.072
.174	.120	.054
.172	.123	.049

$+ 0^{r}.061 = + 6.4$ miles per second.

The computed motion of *Venus* in the line of sight is + 7.69 miles per second.

Arcturus. May 8, 1891.

Comparison of the D_1 line with the Na_1 line of sodium. Grating, 3d spectrum.

Definition of star lines only fair. All measures made with fine wire; observer alternately east and west. By direct comparison the star lines are displaced slightly toward the red.

D_1	Na_1	Diff.
$22^{r}.744$	$22^{r}.740$	$+ 0^{r}.004$
.750	.731	.019
.740	.736	.004
.780	.740	.040
.880	.850	.030
.911	.881	.030
.930	.900	.030
.956	.916	.040
.905	.903	.002
.940	.903	.037
		$+ 0^{r}.024$ = + 2.5 miles per second.

Observed motion of star	+ 2.5 miles per second.
Orbital motion of earth	+ 6.6 miles per second.
Motion of star referred to Sun	— 4.1 miles per second.

G. C. 4390 (*Σ 6*). July 17, 1890.

Comparison of the chief line with the lead line and the magnesium fluting. Grating, 4th spectrum.

By direct comparison the nebular line falls between the lead line and the magnesium fluting, and is distant from the latter by about one fourth of the whole interval.

Neb. Line.	Pb Line.	Diff.
$4^{r}.72$	$4^{r}.12$	$+ 0^{r}.60$
.75	.13	.62
.74	.12	.62
.72	.08	.64
.70	.09	.61
.67*	.01	.66
.78*	.14	.64
		$+ 0^{r}.627$
		= + 1.39 tenth-meters.

Neb. Line.	Mg Fluting.	Diff.
$4^{r}.76$	$4^{r}.98$	$— 0^{r}.22$
.70	.96	.26
.71	.95	.24
.69	.93	.24
.74	.92	.18
		$— 0^{r}.228$
		= — 0.51 tenth-meters.

Observed wave-length of nebular line	5006.99
Correction for earth's motion	— 0.17
Corrected wave-length	5006.82

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* Measures by two other observers.

Nebula of Orion. February 12, 1891.

Comparison of the chief line with the lead line at λ 5005.6. Grating, 4th spectrum.

Nebula near the meridian. Observations about as good as usual.

Neb. Line.	Pb Line.	Diff.
$15^{r}.446$	$14^{r}.495$	$+0^{r}.951$
.383	.450	.933
.400	.463	.937
.373	.430	.943
.400	.455	.945
		$+0^{r}.942$ = + 2.08 tenth-meters.

Wave-length of lead line	5005.63
(N — C) R = △λ = ...	+ 2.08
	5007.71
Earth's motion = 14.5 miles receding=	+ 0.39
Corrected wave-length of chief line	5007.32

Nebula of Orion. February 12, 1891, continued.

Comparison of the third line with the Hβ line of hydrogen. Grating, 4th spectrum.

A new wire, about 0.7 tenth-meter wide, was put in this day for observations of the third nebular line, allowing the slit to be opened twice as wide as before.

By direct comparison the nebular line is displaced by a considerable amount toward the red.

Neb. Line.	Hβ	Diff.
$16^{r}.152$	. . .	$+0^{r}.332$
.195	$15^{r}.820$	.375
.180	. . .	.310
.105	.870	.235
.165	. . .	.340
.095	.825	.270
.082	. . .	.230
.164	.852	.312
.100	. . .	.283
.150	.817	.333
.165	. . .	.335
.165	.830	.335
		$+0^{r}.307$ = + 26.9 miles per second.

Observed motion of nebula	+ 26.9 miles per second.
Orbital motion of earth	+ 14.5 miles per second.
Motion of nebula referred to Sun	+ 12.4 miles per second.

Nebula of Orion. February 12, 1891, continued.

Comparison of the third line with the H$_\beta$ line of hydrogen. Grating, 3d spectrum. Observer alternately east and west.

Neb. Line.	H$_\beta$	Diff.
$16^{r}.068$	. . .	$+\,0^{r}.258$
15 .960	$15^{r}.810$	.150
16 .020	. . .	.176
15 .985	.844	.141
15 .880	. . .	.070
16 .100	.810	.290
15 .966	. . .	.150
16 .053	.816	.237
15 .935	. . .	.125
16 .060	.810	.250
16 .020	. . .	.189
15 .995	.831	.164
		$+\,0^{r}.183 = +$ 26.3 miles per second.

Observed motion of nebula	+ 26.3 miles per second.
Orbital motion of earth	+ 14.5 miles per second.
Motion of nebula referred to Sun	+ 11.8 miles per second.

G. C. 2102. April 29, 1891.

Comparison of the second line with the iron line at λ 4957.63.

Line pretty faint. The coarsest wire (0.7 tenth-meter) is used. By direct comparison the nebular line is considerably below the iron line.

Neb. Line.	Fe Line.	Diff.
$14^{r}.667$	$13^{r}.815$	$+\,0^{r}.852$
.696	.784	.912
.706	.774	.932
.608	.812	.796
.610	.800	.810
		$+\,0^{r}.860 = +$ 1.93 tenth-meters.

Wave-length of iron line	4957.63
(N — C) R = $\triangle\lambda$ = ...	+ 1.93
	4959.56
Earth's motion = 13.4 miles receding = ...	+ 0.36
Corrected wave-length of second line	4959.20

G. C. 4373. September 19, 1890.

Measurement of the interval between the first and second lines.

The method is that described on pages 185–186. The following data are furnished by the observations:

Circle reading on first nebular line	140°	1′	40″
Distance between first and second lines, from ten measures = $\triangle\psi$	1	8	23 ± 6″
Circle reading on reflection of slit	214	32	30
Circle reading on slit	0	1	10

Order of spectrum = n = 4.

Hence, $\psi_1 = 57° \ 15' \ 10''$, $\psi_2 = 56° \ 6' \ 47''$, $\varphi = -17° \ 15' \ 40''$.

For the grating used, $\sigma = \frac{1}{14438}$ in. = 17592.1 tenth-meters.

Substituting in the formulæ for the grating, $\lambda_1 = 5004.1$, which is sufficiently near to its true value, and $\lambda_1 - \lambda_2 = 48.05 \pm 0.07$ tenth-meters.

VII.

OBSERVATIONS OF PLANETS AND STARS.

During the course of the observations of nebulæ, the displacement of lines in the spectra of stars and planets was occasionally observed as a check on the adjustment of the spectroscope. These observations have been collected, and are given below. They were made in precisely the same way as the observations of nebulæ, the lines selected for comparison being usually D and *b*.

In testing the adjustment of a spectroscope on the Moon or other body having no motion in the line of sight, the mere observation that the lines in the direct and reflected spectra are exactly coincident carries but little weight without some statement of the least perceptible displacement. Exact coincidence might be noted with a small single-prism spectroscope, but no measures of motions in the line of sight could be made with it that would have any value.

The measures that accompany such estimates in the following observations show that in the case of a sufficiently bright object, as the Moon or *Venus*, a displacement due to a motion of two miles was perceptible with the Lick Observatory instrument, and the error of a measurement was generally considerably less than this. Some of the nebular lines could be observed with equal accuracy, as will be seen by referring to the examples of measurements in the last section.

A positive sign indicates a motion of recession; a negative sign, approach.

The Moon.

1890, July 3. Exact coincidence of D and *b* lines in third and fourth spectra. No measures.

1890, July 25. Exact coincidence as before.

1890, July 31. Exact coincidence. Measured displacement of the lunar D_1 line (ten settings) gave +0.03 tenth-meter. Another observer from five settings obtained —0.13 tenth-meter.

1890, Aug. 1. Exact coincidence. No measures.

1890, Oct. 23. Exact coincidence. Measured displacement of lunar D_1 line was +0.01 tenth-meter. (Given as an example in the preceding section.)

1891, Jan. 23. Measured displacement of D_1 line was +0.10 tenth-meter. Sky covered with thin clouds, and Moon dim.

Other comparisons made occasionally in the course of the work were not recorded, the results being always the same.

Venus.

Date.	Displacement of D Lines.	Observed Motion.	Computed Motion.	C — O
	r	Miles.	Miles.	Miles.
1890, August 16 . . .	— 0.070	— 7.3	— 8.1	— 0.8
1890, August 22 . . .	— 0.085	— 8.9	— 8.2	+ 0.7
1890, August 22 . . .	— 0.072	— 7.5	— 8.2	— 0.7
1890, August 30 . . .	— 0.070	— 7.3	— 8.3	— 1.0
1890, September 3 . .	— 0.079	— 8.2	— 8.3	— 0.1
1890, September 4 . .	— 0.079	— 8.2	— 8.3	— 0.1
1891, March 21	+ 0.062	+ 6.5	+ 7.9	+ 1.4
1891, April 3	+ 0.061	+ 6.4	+ 7.7	+ 1.3

The second observation of August 22, 1890, was made by Mr. CAMPBELL.

It will be noticed that there is no tendency in these observations to overestimate the amount of the displacement. Each spectrum is observed in the absence of the other.

Jupiter.

1890, July 10. The *b* lines were displaced toward the violet by about half the width of the coarse micrometer wire, or about 0.2 tenth-meter, corresponding to a motion of about — 7 miles per second. The computed motion for the time of observation is — 6.4 miles. Lines quite dim and estimate rough. With the slit coincident with the equator of *Jupiter* the lines were slightly twisted, showing effect of the planet's rotation.

1890, July 17. A displacement of the *b* lines in the third spectrum could be detected when the slit was placed alternately on the east and west limbs of *Jupiter*. The spectrum was very narrow when the limb was observed, and the lines were hard to see. No cylindrical lens was used.

α Boötis.

Date.	Displacement of D Lines.	Observed Motion.	Earth's Motion.	Motion of Star Referred to Sun.
	r	Miles.	Miles.	Miles.
1890, April 10 . . .	— 0.044	— 4.6	— 0.6	— 4.0
1890, August 7 . .	+ 0.100	+ 10.4	+ 14.3	— 3.9
1890, August 15 . .	+ 0.089	+ 9.3	+ 13.3	— 4.0
1891, March 16 . .	— 0.106	— 11.1	— 7.3	— 3.8
1891, March 20 . .	— 0.121	— 12.7	— 6.3	— 6.4
1891, April 2	— 0.053	— 5.5	— 2.9	— 2.6
1891, April 29 . . .	— 0.003	0.0	+ 4.3	— 4.3
1891, May 8	+ 0.024	+ 2.5	+ 6.6	— 4.1
1891, May 14 . . .	+ 0.031	+ 3.2	+ 8.0	— 4.8
				Mean, — 4.2

α Tauri.

Date.	Displacement of D Lines.	Observed Motion.	Earth's Motion.	Motion of Star Referred to Sun.
	r	Miles.	Miles.	Miles.
1890, October 10 . .	+ 0.208	+ 21.7	— 13.9	+ 35.6
1890, October 16 . .	+ 0.236	+ 24.6	— 12.7	+ 37.3
1890, October 30 . .	+ 0.198	+ 20.7	— 9.3	+ 30.0
				Mean, + 34.3

α Orionis.

Date.	Displacement of D Lines.	Observed Motion.	Earth's Motion.	Motion of Star Referred to Sun.
	r	Miles.	Miles.	Miles.
1890, October 10 . .	— 0.062	— 6.5	— 16.5	+ 10.0
1890, October 16 . .	— 0.059	— 6.2	— 15.7	+ 9.5
				Mean, + 9.8

VIII.

OBSERVATIONS OF NEBULÆ.

The Nebula of Orion.

Although the observations of the nebula of *Orion* were among the last which were made, they will be considered first, partly on account of the great interest which attaches to everything relating to this nebula, and partly because it is, with one exception, the only nebula in the sky which was large and bright enough to allow of satisfactory comparisons of the third line with terrestrial hydrogen. As the origin of the chief nebular line is unknown, we have no terrestrial substance with which to make a direct comparison, and a measurement of the position of this line in the spectrum gives us no information as to the motion of the nebula in the line of sight. The normal position of the chief line, or position which it would have if determined by an observer at rest relatively to the nebula, cannot be fixed without a knowledge of the motion of the nebula. In my preliminary paper on the motions of the planetary nebulæ, I was compelled to adopt the mean position of the principal line for the ten nebulæ which I had at that time observed as the normal position from which to measure displacements. If the mean position of the line were taken for a large number of nebulæ distributed with some uniformity throughout the sky, it would probably differ very little from the normal position desired. Ten nebulæ are, however, hardly sufficient for the purpose, particularly when their distribution is not uniform. Fortunately, all difficulties are removed by the observations of the third line in the spectrum of the *Orion* nebula. As the third nebular line is undoubtedly due to hydrogen, its displacement, when compared with the same line produced by gas in a spectrum tube, gives at once the motion of the nebula in the line of sight and the correction which must be applied to the position of the chief line to obtain its normal position.

In observations of the nebula of *Orion* for determining the positions of the spectral lines, the slit was always placed on the bright part of the nebula immediately preceding the trapezium,* one of the trapezium stars being usually kept within the slit at its extreme end. This was done in order to have all the observations refer to one part of the nebula, in case relative motion of the different parts should subsequently be detected. The slit was shortened, so that the length of the bright lines of the nebula was about one-third the diameter of the field.

a. Position of the Chief Line in the Spectrum of the Nebula of Orion.

Date.	Order of Spectrum.	Distance from Lead Line.	Observed Wave-Length.	Correction for Earth's Motion.	λ
		Tenth-Meters.	Tenth-Meters.	Tenth-Meters.	Tenth-Meters.
1890, February 13 .	4	+ 2.13	5007.76	— 0.39	5007.37
1890, February 13 .	3	+ 1.92	5007.55	— 0.39	.16
1890, March 20 . . .	4	+ 2.08	5007.71	— 0.43	.28
1890, October 10 . .	4	+ 1.32	5006.95	+ 0.39	.34
1890, October 16 . .	4	+ 1.51	5007.14	+ 0.36	.50
1890, October 17 . .	4	+ 1.34	5006.97	+ 0.36	.33
1890, October 17 . .	3	+ 1.39	5007.02	+ 0.36	.38
1890, October 23 . .	4	+ 1.49	5007.12	+ 0.33	.45
1890, October 23 . .	3	+ 1.48	5007.11	+ 0.33	.44
1890, October 30 . .	4	+ 1.38	5007.01	+ 0.30	.31
1890, October 30 . .	3	+ 1.34	5006.97	+ 0.30	.27
1891, January 23 . .	3	+ 2.04	5007.67	— 0.30	.37
1891, January 23 . .	4	+ 1.97	5007.60	— 0.30	.30
1891, January 26 . .	4	+ 2.02	5007.65	— 0.31	.34
1891, January 28 . .	4	+ 2.09	5007.72	— 0.32	.40
1891, February 12 .	4	+ 2.08	5007.71	— 0.39	.32
1891, April 3	4	+ 2.04	5007.67	— 0.40	.27
				Mean,	5007.34 ± 0.013

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* Holden's "Region A." Appendix I, Washington Obs. for 1878.

b. Motion of the Orion Nebula in the Line of Sight, from Comparisons of the Third Line with Terrestrial Hydrogen.

Date.	Order of Spectrum.	Displacement of Nebular Line.	Observed Motion of Nebula.	Earth's Motion.	Motion of Nebula Referred to Sun.
		r	Miles.	Miles.	Miles.
1890, October 16 . .	3	− 0.019	− 2.7	− 13.6	+ 10.9
1890, October 23 . .	3	− 0.003	− 0.4	− 12.4	+ 12.0
1890, October 23 . .	3	− 0.019	− 2.7	− 12.4	+ 9.7
1890, October 30 . .	3	− 0.050	− 7.2	− 11.2	+ 4.0
1891, January 23 . .	4	+ 0.241	+ 19.4	+ 11.0	+ 8.4
1891, January 23 . .	3	+ 0.191	+ 25.8	+ 11.0	+ 14.8
1891, January 26 . .	3	+ 0.125	+ 16.9	+ 11.6	+ 5.3
1891, January 28 . .	3	+ 0.233	+ 33.5	+ 12.0	+ 21.5
1891, February 12 .	4	+ 0.307	+ 26.9	+ 14.5	+ 12.4
1891, February 12 .	3	+ 0.183	+ 26.3	+ 14.5	+ 11.8
1891, March 6 . . .	4	+ 0.284	+ 24.9	+ 16.2	+ 8.7
1891, March 18 . .	4	+ 0.338	+ 29.6	+ 16.1	+ 13.5
1891, March 20 . .	4	+ 0.300	+ 26.3	+ 16.1	+ 10.2
				Mean,	+ 11.0 ± 0.8

From these observations of the third line it appears that the nebula of *Orion* is receding from the Sun at the rate of 11.0 ± 0.8 miles per second. It may be that this motion of recession is wholly due to the drift of the solar system itself. The supposition seems plausible (though certainly no good reason could be given for it) that a nebula of such vast extent and extreme tenuity is more likely to be at rest relatively to the stars of our system than small, compact, nebular masses or individual stars. This view is at least not inconsistent with determinations of the direction and amount of the solar motion based on proper motions of the stars. The most recent investigations of Professor BOSS* place the apex of the Sun's way in R. A. 280° and Dec. + 40°. Professor BOSS also considers that the velocity of the solar motion may be as low as 15 miles, or as high as 30 miles, but that it is much more likely to be included between 20 and 28 miles per second. Calling the velocity 25 miles, the recession of the solar system from the nebula of *Orion* would be 15.5 miles per second.

On the other hand, assuming the recession of the nebula which is given by these spectroscopic observations, and BOSS' position of the apex of the Sun's way, and further that the *Orion* nebula has no motion relatively to the center of figure of our stellar system, the velocity of the Sun's proper motion would be 17.7 miles per second.

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c. Normal Position of the Chief Nebular Line.

On account of the recession of the *Orion* nebula from the Sun at the rate of 11.0 miles per second, the third line in the spectrum of the nebula is displaced toward the red by 0.29 tenth-meter, and the chief line is displaced in the same direction by 0.29+ tenth-meter. Hence, the position of the chief line, if determined by an observer at rest relatively to the nebula, would be λ 5007.34 — 0.29 = λ 5007.05, and this, therefore, is the *normal position* of the chief nebular line. By comparing the place of the chief line in the spectra of other nebulæ with this position, the motions of such nebulæ can be deduced.

The probable error of the normal position is, by the theory of least squares, ± 0.03 tenth-meter.

d. Relative Motion of Different Parts of the Orion Nebula.

The results of these observations were purely negative. The method was to occult the chief line in the spectrum of the bright part preceding the trapezium with the coarse micrometer wire (0.35 tenth-meter), then move the telescope slowly, by its slow-motion screws, so as to bring other parts of the nebula upon the slit, and note if the bright line appeared from behind the wire. No such displacement was ever noticed. How small a displacement could be observed in this way is uncertain, as in the fainter parts of the nebula the line was very dim, and the method worthless, but it is evident that a difference of motion of 13 miles per second would have thrown the nebular line entirely clear of the wire, and in the brighter parts of the nebulæ a third of this displacement could have been detected.

e. Aspect of the Nebular Lines, and Other Observations.

During the course of these measurements the nebular lines were frequently examined, with both the large and the smaller spectroscopes, with reference to the character of the lines, and particularly to the fluted aspect described by Professor LOCKYER. The lines always appeared perfectly fine and sharp; the hydrogen lines from the spectrum tube were not finer and sharper. When the chief line was occulted by the micrometer wire, the least haziness on one side would have been quite noticeable, but nothing more than the ordinary symmetrical illumination due to diffraction was ever seen. The lines were also examined with the small spectroscope on the 12-inch equatorial, with the same result. With this spectroscope on the 36-inch equatorial a slight fringe was once suspected on the more refrangible side of the chief line, but experiment showed that this appearance was due to the line being considerably out of the center of the field, as a fringe appeared on the less refrangible side of the line when the line was displaced equally on the other side of the center, and all fringes disappeared when the line was central.

The continuous spectrum of the nebula was easily visible (with a single prism), although it is not so bright as in many other nebulæ. I have never been able to see the D_3 line in the spectrum of the nebula of *Orion*.

Inside the trapezium the lines appeared pretty nearly the same as elsewhere in the vicinity, and hence the darker background within the trapezium when the nebula is seen with an ordinary eye-piece would appear to be merely an effect of contrast.

With the grating, the continuous spectrum of a trapezium star was apparently decidedly brighter where it was crossed by one of the nebular lines,[*] thus confirming the photographic results of Dr. and Mrs. HUGGINS[†] with regard to the physical connection between the nebula and the stars of the trapezium. The star ϑ_2 *Orionis*,[‡] however, which is also involved in the nebula, has the hydrogen lines dark. The lines in the spectrum of the nebula surrounding BOND'S No. 734 were much too faint for observation with the grating.

f. Position of the Second Line.

On March 18, 1891, the angular distance between the first and second lines in the fourth spectrum was measured, and at the same time the necessary observations were made for determining the position of the grating, so that by the formulæ for the grating the difference of wave-length of the two lines could be determined. The resulting value for $\Delta\lambda$ was 48.13 tenth-meters, and hence the wave-length of the second line, corrected for orbital motion of the earth, is, by this observation, λ 4959.21.

One comparison of the second line with iron gave the following result:

Date.	I	Observed λ	Reduc. to Sun.	λ
1891, April 2	+ 2.10	4959.73	— 0.40	4959.33

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[*] See note at the end of this paper. The appearance described is no doubt illusory.

[†] *Proc. Roy. Soc.*, vol. 46, p. 41.

[‡] BOND'S No. 685.

OBSERVATIONS OF NEBULÆ.

G. C. 116.

$$\left.\begin{array}{r}\text{R. A.} = 0^h\ 36^m\ 45^s \\ \delta = +\ 40^\circ\ 40'\end{array}\right\}$$

The spectrum of the great nebula of *Andromeda* was examined with the small spectroscope attached to the 36-inch equatorial, but nothing was seen except a faint continuous spectrum. On the same night it was removed and placed on the 12-inch refractor, thus making the effective aperture of the spectroscope 0.67 instead of 0.53 inch, and gaining the advantage of a thin object-glass. The spectrum was then considerably brighter. It seemed to terminate rather abruptly at the lower end, but this impression may have been merely subjective, as the spectrum of any faint white light (the sky on a moonlight night, for instance) has to me the same appearance. By moving the spectrum until its lower end just touched the edge of the field, and then holding a light in front of the slit, it was estimated that the spectrum really extended some distance into the red, perhaps nearly to the $H\alpha$ line.

Mr. BARNARD, who observed with me, suspected a brightening in the green above the chief maximum just below, "the suspicion almost amounting to certainty." After Mr. BARNARD had pointed it out I thought I could perceive this second maximum also. This observation was made with special reference to the carbon flutings which Mr. LOCKYER and his assistants considered to be present in the spectrum of the *Andromeda* nebula. It seems to me, however, that admitting the reality of the brightenings observed by Mr. BARNARD and myself, their identification with the flutings of carbon, or any spectral flutings or lines whatever, is subject to very great uncertainty. For a trustworthy comparison, the spectrum would evidently have to be seen to very much greater advantage than in the observations described above, although a consideration of the dimensions and optical constants of the spectroscope will show that it was an efficient instrument for the observation of bright lines. With a smaller dispersion than that of a 60° prism the spectrum would be brighter, but apparent coincidence of lines would then have little meaning.

G. C. 826.

$$\left.\begin{array}{r}\text{R. A.} = 4^h\ 9^m\ 8^s \\ \delta = -\ 13^\circ\ 1'\end{array}\right\}$$

This is a large, dim planetary nebula, with ill-defined edges and a small nucleus. HUGGINS, in 1864, noted that the spectrum was continuous; but this is evidently a mistake, as the usual lines were seen with the small spectroscope, and with the grating the chief line was bright enough for a rough measure.

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1891, January 26 . .	+ 1.65	. . . .	5007.28	— 0.40	5006.88

G. C. 1366.

R. A. = 6^h 3^m 6^s }
δ = + 20° 30′ }

This is a nebulous star of the 7.7 magnitude. It was examined only once, with the small spectroscope, on a bright moonlight night, when nothing could be seen of the nebulosity. With an ordinary eye-piece the star was yellowish. No lines were seen in its spectrum.

G. C. 2102.

R. A. = 10^h 19^m 29^s }
δ = — 18° 5′ }

This is one of the brightest and most beautiful of the large planetary nebulæ. It is elliptical, 42″.4 x 38″.3 (according to measures by Mr. **Burnham**), the major axis being in position-angle 145°. The edge is brighter than the disc, forming a kind of rim. There is a very bright inner ring, which shows the bluish color of these nebulæ very beautifully. Its inner outline is nearly circular, and the outer boundary is elliptical (23″ x 17″), the major axis being parallel to that of the main nebula. Exactly in the center is a fairly bright nucleus.

The following are measures of the position of the principal line in its spectrum:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1891, March 18 . . .	+ 1.64	. . . .	5007.27	— 0.10	5007.17
1891, March 20 . . .	+ 1.55	. . . .	5007.18	— 0.11	5007.07
1891, April 2 . . .	+ 1.87	. . . .	5007.50	— 0.20	5007.30
1891, April 3 . . .	+ 1.72	. . . .	5007.35	— 0.21	5007.14
1891, April 29 . . .	+ 1.79	. . . .	5007.42	— 0.36	5007.06
				Mean,	5007.15

Measures of the position of the second line, by comparison with the iron line, have been made as follows:

Date.	I	Observed λ	Reduc. to Sun.	λ
1891, April 2 . . .	+ 1.64	4959.27	— 0.20	4959.07
1891, April 3 . . .	+ 1.50	4959.13	— 0.21	4958.92
1891, April 29 . . .	+ 1.93	4959.56	— 0.36	4959.20
			Mean,	4959.06

a. Attempt to Detect a Motion of Rotation of G. C. 2102.

On April 3d an attempt was made to determine whether this nebula had any sensible motion of rotation. The method was that already described in connection with observations of the relative motion of different parts of the *Orion* nebula. The results were purely negative. No change of position of the chief line could be detected on passing from one limb of the nebula to the opposite one, with the slit in different position-angles. The bright inner ring was also observed in the same way without result. It is doubtful whether a smaller difference of motion than 7 or 8 miles a second could have been detected, and it is perhaps improbable that a nebula should have so large a motion of rotation as this.

G. C. 2343.

$$\left.\begin{array}{l}\text{R. A.} = 11^{h}\ 8^{m}\ 25^{s} \\ \delta = +\ 55^{\circ}\ 37'\end{array}\right\}$$

A very large, dim planetary nebula, with ill-defined edges. In the center is a small nucleus of the 14th magnitude, and the central part of the nebula is comparatively dark. The drawing by Lord ROSSE in *Philosophical Transactions*, 1850, plate 37, does not at all represent the appearance of this nebula in the 36-inch equatorial. There is but one nucleus, which is by estimate (and also according to Mr. BURNHAM'S measures) almost exactly central, at a place which in Lord ROSSE'S drawing is occupied by a bridge of light between two dark openings. There is also but one central dark space.

The spectrum is of the usual gaseous type, but the chief line could not be seen with the large spectroscope.

G. C. 3193 (?).

$$\left.\begin{array}{r}\text{R. A.} = 12^{h}\ 39^{m}\ 0^{s} \\ \delta = +\ 11^{\circ}\ 46'\end{array}\right\}$$

I am not sure that this is the nebula actually observed, as it is in the nebulous region in *Virgo*, and the telescope was not set very carefully. However, a number of nebulæ in the vicinity were examined with the small spectroscope, and they all gave a continuous spectrum, which was brighter and more extensive at the center of the nebula. The center, though bright and condensed, was not marked by a distinct nucleus. No bands or bright lines were seen.

G. C. 4058.

$$\left.\begin{array}{r}\text{R. A.} = 15^{h}\ 3^{m}\ 28^{s} \\ \delta = +\ 56^{\circ}\ 11'\end{array}\right\}$$

This spindle-shaped nebula is divided lengthwise by a narrow, perfectly dark, straight rift, on each side of which, near the n. p. end, and involved in the nebulosity, is a minute star of about the 16th magnitude. The drawing by Lord ROSSE in *Philosophical Transactions*, 1850, plate 37, fig. 8, represents very well the appearance of this nebula in the 36-inch refractor.

The continuous spectrum was examined, with special reference to flutings of carbon, with the small spectroscope on July 18, 1890, but it was excessively faint, and no details could be seen. The light seemed to end rather abruptly at the lower end of the spectrum, in the orange, as in the spectrum of the nebula of *Andromeda*.

G. C. 4234 (Σ 5).

$$\left.\begin{array}{r}\text{R. A.} = 16^{h}\ 39^{m}\ 53^{s} \\ \delta = +\ 24^{\circ}\ \ 0'\end{array}\right\}$$

This nebula was first examined on May 15, 1890. It is nearly round, and has a bright stellar nucleus giving a continuous spectrum, in which a bright line at D_3 was suspected on one occasion. The nebular lines are fine and bright, although less sharply defined than in the nebula of *Orion*. Outside the nebula, but connected with it by a faint band of light, is a condensation of nebulosity, the spectrum of which is like that of the main nebula.

The following measures have been made:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, June 13 . . .	. . . .	— 0.72	5006.75	— 0.11	5006.64
1890, June 27 . . .	. . . .	— 0.77	5006.70	— 0.18	5006.52
1890, June 27 . . .	. . . .	— 0.82	5006.65	— 0.18	5006.47
1890, July 3	+ 0.99	. . . .	5006.62	— 0.21	5006.41
1890, July 4	+ 1.02	. . . .	5006.65	— 0.21	5006.44
1890, July 10	+ 1.02	. . . .	5006.65	— 0.24	5006.41
1891, April 29 . . .	+ 0.61	. . . .	5006.24	+ 0.14	5006.38
1891, May 8	+ 0.81	. . . .	5006.44	+ 0.09	5006.53
1891, May 14 . . .	+ 0.84	. . . .	5006.47	+ 0.06	5006.53
				Mean,	5006.48

G. C. 5851.

$$\left.\begin{array}{r} \text{R. A.} = 17^{h}\ 7^{m}\ 53^{s} \\ \delta = -\ 12^{\circ}\ 47' \end{array}\right\}$$

The following measures were made in the third spectrum. The brightest line was excessively faint in the large spectroscope, and the measures are rough:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, August 15 . .	+ 1.00	. . . .	5006.63	— 0.44	5006.19

G. C. 4355.

$$\left.\begin{array}{r} \text{R. A.} = 17^{h}\ 55^{m}\ 43^{s} \\ \delta = -\ 23^{\circ}\ \ 2' \end{array}\right\}$$

The spectrum of this (*Trifid*) nebula is continuous, but short, being apparently confined to the green and blue, and there is a brightening near the middle of it, the wave-length of which could not be estimated with the small spectroscope. The brightest star involved gave a spectrum without lines, although if there had been dark lines as strong as in the average star of Class I they could probably have been seen.

G. C. 4361.

$$\left.\begin{array}{r} \text{R. A.} = 17^{h}\ 56^{m}\ 56^{s} \\ \delta = -\ 24^{\circ}\ 23' \end{array}\right\}$$

The lines were much too faint for observation with the large spectroscope. Examined with the smaller instrument on August 21, 1890, three bright lines were seen, which were probably the usual nebular lines, although the two lowest seemed to be very close. No opportunity occurred for measuring the interval with a prism. The nebula is full of knots or condensations, having the same spectrum as its more diffuse portions, and many bright stars are involved in it, in the spectra of which no lines could be detected.

G. C. 4373.

$$\left.\begin{aligned}\text{R. A.} &= 17^h\,58^m\,35^s\\ \delta &= +\ 66°\ 38'\end{aligned}\right\}$$

The appearance of this, in so many ways remarkable nebula, as seen with the 36-inch equatorial, has been described by Professors HOLDEN and SCHAEBERLE.[*] The chief line falls higher in the spectrum than in any of the other nebulæ I have examined, being nearly in coincidence with the lead line. Measures of its position have been obtained, as follows:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, July 4	+ 0.29	— 1.55	5005.92	0.00	5005.92
1890, July 10	+ 0.29	— 1.66	5005.87	0.00	5005.87
1890, July 25 † . . .	+ 0.55	— 1.13	5006.26	0.00	5006.26
1890, August 15 . .	+ 0.35	— 1.55	5005.95	0.00	5005.95
1890, August 22 . .	+ 0.33	— 1.55	5005.94	0.00	5005.94
1891, May 15	+ 0.27	. . . .	5005.90	0.00	5005.90
				Mean,	5005.97

The position of the second line with reference to the first line was determined on two nights by the method explained in Section IV, with the following results:

1890, September 18, $\Delta\lambda = 47.92$ tenth-meters.
1890, September 19, $\Delta\lambda = 48.05$ tenth-meters.

The mean value of the interval, which is evidently the same as in other nebulæ, places the second line in the spectrum of this nebula at λ 4957.98.

The position of the second line was also determined with reference to the iron line by micrometer measures on two nights.

Date.	I	Observed λ	Reduc. to Sun.	λ
1891, May 14	+ 0.35	4957.98	0.00	4957.98
1891, May 15	+ 0.34	4957.97	0.00	4957.97
			Mean,	4957.98

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[*] *Monthly Notices R. A. S.*, vol. 48 (1888), p. 388.

[†] Poor observations; a violent wind shaking the telescope.

These measures accord with the results for the first line, in showing a large displacement of the nebular lines from the normal position toward the violet.

On July 19, 1890, the spectrum of the nucleus was examined with the small spectroscope, but nothing remarkable could be seen. Although there were indications of bright knots on the continuous spectrum below the chief line, they were not sufficiently distinct for a trustworthy estimate of their positions. The strongest brightening seemed to be about as far below the chief line as the third line is above it, or at about λ 5200. A line is seen at or near this place in *N. G. C. 7027*, and a number of other nebulæ. It is possible that this may be VOGEL's line at 518. The other lines described by VOGEL as *Spuren von Lichtlinien*, at 527, 509, 579, could not be seen. Nothing could be seen of D_3.

N. G. C. 6537.

$$\left.\begin{array}{l}\text{R. A.} = 17^h\ 58^m\ 42^s \\ \delta = -\ 19^\circ\ 51'\end{array}\right\}$$

The brightest line was too faint for observation with the large spectroscope.

G. C. 4390 (Σ *6*).

$$\left.\begin{array}{l}\text{R. A.} = 18^h\ 6^m\ 45^s \\ \delta = +\ 6^\circ\ 50'\end{array}\right\}$$

This is a very bright nebula, and in the summer of 1890 the telescope was usually directed to it, in order to verify the adjustment of the spectroscope before beginning work on other nebulæ. Hence, the position of the chief line has been determined with much accuracy. The measures are as follows:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, July 10	+ 1.41	— 0.40	5007.06	— 0.12	5006.94
1890, July 17	+ 1.39	— 0.51	5006.99	— 0.17	5006.82
1890, July 24	. . . .	— 0.29	5007.18	— 0.22	5006.96
1890, July 25	. . . .	— 0.33	5007.14	— 0.22	5006.92
1890, July 25	. . . .	— 0.29	5007.18	— 0.21	5006.97
1890, July 31	+ 1.52	— 0.31	5007.16	— 0.26	5006.90
1890, August 1 . . .	. . . .	— 0.33	5007.14	— 0.27	5006.87
1890, August 7 . . .	. . . .	— 0.29	5007.18	— 0.29	5006.89
1890, August 8 . . .	. . . .	— 0.22	5007.25	— 0.30	5006.95
1891, April 29 . . .	+ 0.90	. . . .	5006.55	+ 0.34	5006.89
1891, May 8	+ 0.96	. . . .	5006.59	+ 0.30	5006.89
1891, May 14	+ 0.93	. . . .	5006.56	+ 0.26	5006.82
1891, May 22	+ 0.95	. . . .	5006.58	+ 0.22	5006.80
				Mean,	5006.89

The first and second lines in the spectrum of this nebula are very bright. When the first line in the fourth spectrum was made only twice the width of the coarse micrometer wire, the wire was distinctly visible upon the bright background. The third line is also remarkably bright—much brighter by estimation than the same line in the spectrum of the nebula of *Orion;* but an attempt to compare it with the H_β line of hydrogen in the summer of 1890 was not very successful, as the extreme shortness of the line makes the observation more difficult than one might expect in consideration of its brightness. The measurements were rough, and the results discrepant. By simply using a wider slit and wider micrometer wire, very satisfactory comparisons were made on two nights in the spring of 1891. It was considered at the time that they were quite equal in accuracy to those of the nebula of *Orion.* The observations are given below in full, on account of their importance in giving an independent determination of the normal position of the chief nebular line.

G. C. 4390 (Σ *6*). May 21, 1891.

Comparison of the third line with the H_β line of hydrogen. Grating, 4th spectrum. Coarsest wire, 0.7 tenth-meter. The nebular line is displaced toward the violet.

Neb. Line.	H_β	Diff.
$16^{r}.663$	$16^{r}.820$	$-0^{r}.157$
.666	.842	.176
.690	.831	.141
.640	.841	.201
.647	.848	.201
.696	.859	.163
.702	.848	.146
.706	.850	.144
.640	.836	.196
.670	.837	.167

$-0^{r}.169 = -$ 14.8 miles per second.

Observed motion of nebula . . . . — 14.8 miles per second.
Orbital motion of earth . . . . — 8.0 miles per second.

Motion of nebula referred to Sun . . . . . — 6.8 miles per second.

G. C. 4390 (Σ *6*). May 22, 1891.

Comparison of the third line with the H_β line of hydrogen. Grating, 4th spectrum.

Circumstances of observation in all respects the same as those of May 21st.

Neb. Line.	Hβ	Diff.
$16^r.172$	$16^r.355$	$-0^r.183$
.183	.338	.155
.140	.328	.188
.125	.356	.231
.205	.359	.154
.195	.355	.160
.160	.333	.173
.226	.346	.120
.175	.351	.176
.245	.336	.091
		$-0^r.163 = -14.3$ miles per second.

Observed motion of nebula	— 14.3 miles per second.
Orbital motion of earth	— 8.0 miles per second.
Motion of nebula referred to Sun	— 6.3 miles per second.

a. Normal Position of the Chief Nebular Line, from Observations of G. C. 4390.

These observations of *G. C. 4390* give an independent determination of the normal position of the chief nebular line. As the nebula is approaching the Sun at the rate of 6.55 miles per second, the chief line is displaced toward the violet by 0.18 tenth-meter. Hence the normal position of the chief line, by observations of *G. C. 4390* is $\lambda\,5006.89 + 0.18 = \lambda\,5007.07$. The close agreement between this result and that derived from observations of the nebula of *Orion* is especially satisfactory, as one of the nebulæ is approaching the Sun, the other receding from it, and they are situated in diametrically opposite quarters of the heavens.

Viewed with an ordinary eye-piece, the nucleus of *G. C. 4390* does not appear perfectly sharp, but seems to blend into the surrounding nebula. An examination of its spectrum with the small spectroscope confirmed this view as to the absence of any marked boundary between the nebula and its nucleus, the continuous spectrum of the latter shading off somewhat gradually into that of the nebula, and showing a great increase in brilliancy where it was crossed by the nebular lines. Besides the usual lines 5007, 4959, Hβ, and Hγ, several others were seen in the spectrum of the nucleus. A line near D was quite bright, and a comparison with the sodium line from a spirit lamp showed that it was probably D_3. Hα was seen with great difficulty at the extreme lower end of the spectrum. Other faint bright lines appeared at about 5680, 5400, and 4450, the positions being mere eye-estimates, and dark bands were suspected at two or three places between the brightest line and D_3. The principal lines were fine and sharp in the spectrum of the nebula, but fuzzy and considerably broadened in that of the nucleus. It would evidently be a matter of considerable interest to note whether the bright lines D_3, Hα, and other of the less conspicuous lines, appear only in the nucleus, where the substances in which they have their origin are doubtless subjected to greater temperature and pressure, or whether the lines do not appear in the spectrum of the more diffuse parts of the nebula, simply on account of their faintness. It was very hard to determine this point. The lines were very short—mere knots on the spectrum of the nucleus—but they certainly seemed to fade outward from the nucleus much more rapidly than the ordinary nebular lines.

The second line was compared with iron on three nights, the results being as follows:

Date.	I	Observed λ	Reduc. to Sun.	λ
1891, April 29 . . .	+ 0.96	4958.59	+ 0.34	4958.93
1891, May 8	+ 0.94	4958.57	+ 0.29	4958.86
1891, May 14 . . .	+ 1.01	4958.64	+ 0.26	4958.90
			Mean,	4958.90

On May 21, 1891, the interval between the first and second lines was measured in the fourth spectrum of the grating, and was found to be 47.89 tenth-meters.

G. C. 4447.

$$\left.\begin{array}{l}\text{R. A.} = 18^{\text{h}}\ 49^{\text{m}}\ 30^{\text{s}} \\ \delta = +\ \ 32^{\circ}\ 54'\end{array}\right\}$$

The brightest line in the spectrum of the ring nebula in *Lyra* was too faint for measurement with the grating. With the small spectroscope the three usual nebular lines were seen, although the third line was quite faint. My first impression, on looking at the spectrum with this instrument, was, that the chief line was disproportionately bright as compared with the second, but a careful examination with the large spectroscope, using the grating, and a slit so wide that the lines appeared almost as monochromatic images of the nebula, convinced me that this impression was erroneous, and that the first and second lines had the usual ratio of brightness. With the grating the third line was not visible.

The central star has always been easily visible whenever I have looked at this nebula with the 36-inch refractor, but it is too faint for observation with a spectroscope. A rough idea of the nature of its spectrum can, however, be obtained by the aid of the telescope alone. Owing to the chromatic aberration of the large telescope, the focus for rays having a wave-length of λ 5000 is about a quarter of an inch outside the minimum focus, which is that of the brightest rays of the spectrum, in the greenish-yellow.* Hence, a planetary nebula and its stellar nucleus cannot be seen distinctly at the same time. The same difference of focus is required for the *Lyra* nebula and its nucleus as for other nebulæ, showing that the greater part of the light of the nucleus is in the lower part of the spectrum, and that therefore the central star does not differ materially in the character of its light from the nucleus of an ordinary planetary nebula. This fact is mentioned here because it has been inferred, from some supposed peculiarity in the photographic action of the central star, that the light of the star consists mainly of blue and violet rays. The peculiarity referred to may be due to bright lines in the upper part of the spectrum.*

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* See the table in Section II.

N. G. C. 6790 (= DM. + 1°.3979).

$$\left.\begin{array}{l} \text{R. A.} = 19^{h}\ 17^{m}\ 20^{s} \\ \delta = +\quad 1^{\circ}\ 18' \end{array}\right\}$$

This is one of the very small stellar planetary nebulæ discovered by Professor Pickering. It is rated in the DM. as 9.4 mag.; is round, bright, and has a very minute nucleus, the general appearance of the nebula being much like that of *G. C. 4390* on a smaller scale. The third line is, however, relatively quite faint, and in this respect the nebula resembles *N. G. C. 7027*. Without a slit the spectrum of *N. G. C. 6790* looks like a row of three small stars.

In this nebula the brightest line falls lower in the spectrum than in any nebula I have yet examined, with perhaps the single exception of *N. G. C. 6891*, the observations of which are of doubtful accuracy. The line is *less* refrangible than the edge of the magnesium fluting, a fact which was seen at once in a direct comparison, and which is also shown by the following measures:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, July 31	+ 2.30	+ 0.46	5007.93	— 0.14	5007.79
1890, August 1 . . .	+ 2.45	+ 0.44	5008.00	— 0.15	5007.85
1890, August 8 . . .	+ 2.51	. . . .	5008.14	— 0.20	5007.94
				Mean,	5007.86

With the small spectroscope a bright point at the estimated position of D_3 was seen occasionally, on the faint continuous spectrum of the nucleus, and between this and the chief line two faint brightenings were suspected, one of them at about λ 5200.

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* See A. N. 3086 and A. N. 3111. (Note added May 1, 1894.)

G. C. 4510.

$$\left.\begin{array}{r}\text{R. A.} = 19^{\text{h}}\ 37^{\text{m}}\ 46^{\text{s}} \\ \delta = -\ 14^{\circ}\ 25'\end{array}\right\}$$

The intrinsic brilliancy of this large planetary nebula is small, and the measures were difficult. Those of August 8 were made in the third spectrum, and as the slit was wider than usual, the comparisons with the lead line are much more reliable than those with the magnesium fluting.

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, July 17	+ 1.33	— 0.91	5006.76	— 0.02	5006.74
1890, August 8 . . .	+ 1.37	— 0.48	5006.99	— 0.19	5006.80
				Mean,	5006.77

G. C. 4514.

$$\left.\begin{array}{r}\text{R. A.} = 19^{\text{h}}\ 41^{\text{m}}\ 51^{\text{s}} \\ \delta = +\ 50^{\circ}\ 16'\end{array}\right\}$$

The large, round, fairly bright disc of this nebula is apparently without structure. The nucleus is very bright, and was examined with the small spectroscope in the expectation of finding a complicated bright-line spectrum. The spectrum was, however, continuous, and although bright points could be glimpsed in it, their positions could not be determined. In the large spectroscope the nebular lines were quite dim.

The following measures have been obtained:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, July 25	+ 1.54	— 0.55	5007.04	— 0.02	5007.02
1890, August 15 . .	+ 1.39	— 0.57	5006.96	0.00	5006.96
1890, October 10 . .	+ 1.38	. . . .	5007.01	— 0.14	5006.87
1890, October 16 . .	+ 1.51	. . . .	5007.14	— 0.16	5006.98
				Mean,	5006.96

G. C. 4532.

$$\left.\begin{array}{r}\text{R. A.} = 19^{\text{h}}\ 54^{\text{m}}\ 51^{\text{s}} \\ \delta = +\ 22^{\circ}\ 25'\end{array}\right\}$$

The lines in the spectrum of the Dumb-bell nebula were too faint for observation with a grating. No observations were made with the small spectroscope.

N. G. C. 6891.

R. A. = $20^h\ 9^m\ 57^s$
$\delta = +\ 12^\circ\ 24'$

This is a small and rather faint nebula (described as "stellar, 9.5 mag.," in the *N. G. C.*), with a very small nucleus. A star in the same parallel is just outside the nebula.

The chief line was faint with the grating, and the slit had to be opened wide. Hence, the measurements are not very reliable, but the line was certainly very low in the spectrum. Measures were made on only two nights.

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, October 16 . .	+ 2.37	. . . .	5008.00	— 0.41	5007.59
1890, October 17 . .	+ 2.66	. . . .	5008.29	— 0.42	5007.87
				Mean,	5007.73

G. C. 4572.

R. A. = $20^h\ 17^m\ 29^s$
$\delta = +\ 19^\circ\ 45'$

This is a large, pale, planetary nebula with a small nucleus. On each side is a small star close to the edge of the nebula. The brightest line was just visible in the large spectroscope, and no measurements could be made.

G. C. 4628.

R. A. = $20^h\ 58^m\ 11^s$
$\delta = -\ 11^\circ\ 48'$

This is a large, round nebula, with a bright inner ring, which is considerably elongated in an east-and-west direction, and a very small nucleus. Its appearance in the 36-inch telescope has been described by Professor HOLDEN and Professor SCHAEBERLE.* The following measures were obtained with the large spectroscope. Those of July 31, 1890, were rather difficult on account of the bright moonlight on the floor around the observer:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, July 31	+ 0.66	— 1.13	5006.31	+ 0.04	5006.35
1890, August 22 . .	+ 0.71	— 0.88	5006.44	— 0.14	5006.30
1890, October 10 . .	+ 0.93	. . . .	5006.56	— 0.45	5006.11
1890, October 16 . .	+ 1.01	. . .	5006.64	— 0.47	5006.17
1890, October 23 . .	+ 1.03	. . . .	5006.66	— 0.48	5006.18
				Mean,	5006.22

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* *Monthly Notices R. A. S.*, vol. 48 (1888).

N. G. C. 7026.

$$\left.\begin{array}{r}\text{R. A.} = 21^h\ 2^m\ 35^s \\ \delta = +\ 47^\circ\ 24'\end{array}\right\}$$

The shape of this nebula as seen with the 36-inch equatorial somewhat resembles two sheaves of grain laid side by side. In the middle of each sheaf is an ill-defined nucleus.

The spectrum is of the usual type, but the lines were too faint for observation with the grating.

N. G. C. 7027 (= DM. + 41°.4004).

$$\left.\begin{array}{r}\text{R. A.} = 21^h\ 2^m\ 55^s \\ \delta = +\ 41^\circ\ 48'\end{array}\right\}$$

This is the brightest nebula that I have examined, and its spectrum is exceedingly interesting. The nebula is irregular in outline, and contains two central condensations, one of which has an oval and fairly-well defined outline. The other is much fainter and more diffuse. On the following side is a small star, just at the border of the nebula. The spectrum was examined on August 21, 1890, with the small spectroscope. The chief line is *brilliant*, the second also very bright, but the hydrogen lines are relatively dim, and an attempt to compare the third line with H_β, with the large spectroscope, failed. On widening the slit, a monochromatic image of the central condensation could be seen in the brightest line, in much the same way that a prominence is seen in the H_α line of the solar spectrum. It was perfectly sharp and well defined on all sides, and one might easily suppose that it was the nebula itself seen with an ordinary eye-piece. This image became a mere knot or brightening on the chief line when the slit was narrowed. The continuous spectrum of the nebula showed but a comparatively slight brightening at the nucleus, which is evidently in a much less condensed state than the nuclei of Σ *6* and many other nebulæ of its kind, a fact of much interest considering the brilliancy of the nucleus. Several bright lines below the strong group in the green were visible in the spectrum of the central condensation only, probably on account of their faintness. One of these, the lowest visible, was in the estimated position of D_3; another, very well seen, was at about λ 5400, and between this and the brightest line were several others, of which the only one that could be definitely fixed was at about λ 5200. It should be remembered that these positions are from mere eye-estimates, using the intervals between known lines as terms of comparison. This nebula also shows the line at about λ 4700, which is visible in the spectrum of *G. C. 4964*. With the grating this line could not be seen.

With the large spectroscope measures of the position of the brightest line were obtained, as follows:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, August 15 . .	+ 1.57	— 0.35	5007.16	+ 0.07	5007.23
1890, August 22 . .	+ 1.55	— 0.20	5007.22	+ 0.03	5007.25
1890, October 9 . .	+ 1.80	— 0.12	5007.39	— 0.18	5007.21
1890, October 10 . .	+ 1.76	. . . .	5007.39	— 0.18	5007.21
				Mean,	5007.22

A few measures of the position of the second line have been made. On September 3, 1890, the angular distance between the first and second lines in the fourth spectrum of the grating was measured five times, the resulting difference of wave-length being 48.07 tenth-meters.

Ten measures of the same interval on September 19, gave $\Delta\lambda = 47.82$. Taking as the result of both nights $\Delta\lambda = 47.90$, the position of the second line is λ 4959.32.

A comparison of the second line with iron was made on one night, with the following results:

Date.	I	Observed λ	Reduc. to Sun.	λ
1891, May 15 . . .	+ 1.25	4958.88	+ 0.27	4959.15

G. C. 4964.

$$\left.\begin{aligned} \text{R. A.} &= 23^{\text{h}}\ 20^{\text{m}}\ 27^{\text{s}} \\ \delta &= +\ \ 41^{\circ}\ 56' \end{aligned}\right\}$$

This nebula is annular, with a bright inner ring and a very small nucleus. It is somewhat elongated north and south.

The spectrum shows, in addition to the two brightest nebular lines and the hydrogen lines H_β and H_γ, a line at about λ 4700, which was seen by HUGGINS in his first spectroscopic observations of nebulæ, in 1864. Examined with the small spectroscope on August 21, 1890, no other lines than the above were seen. The lines showed bright knots where the inner ring of the nebula was crossed by the slit. The spectrum of the nucleus was excessively faint, but there was a broad, faint, continuous spectrum, due to the nebula itself.

The following are measures with the large spectroscope:

Date.	L	M	Observed λ	Reduc. to Sun.	λ
1890, August 1 . .	+ 1.19	— 0.95	5006.67	+ 0.32	5006.99
1890, August 7 . .	+ 0.80	— 1.04	5006.43	+ 0.30	5006.73
				Mean,	5006.86

IX.

MOTIONS OF NEBULÆ IN THE LINE OF SIGHT.

The observations which are described in the preceding section show that the position of the chief nebular line, corrected for the effect of the earth's motion, is not the same in the spectra of different nebulæ. These differences of position, which are many times greater than the errors of observation, can only be due to motion of the nebulæ toward or away from the Sun, as in all nebulæ the line unquestionably has its origin in the same substance. Dr. HUGGINS,* in 1874, sought to determine the motions of the nebulæ by the same method, but his instrumental means were insufficient for the purpose.

In the following table are given the motions of a number of different nebulæ in the line of sight, deduced from the displacement of the chief line from its normal position, together with the probable errors of measurement. The probable error of the displacement and motion in the line of sight includes that of the normal position deduced from observations of the *Orion* nebula and *G. C. 4390*. In the case of a nebula which has been observed on only two or three nights, the probable error which has been assigned is that of the same number of measurements of a nebula equally bright, determined from a consideration of all the observations. Dividing the nebulæ roughly into two classes, very bright and bright, we find, approximately:

For very bright nebulæ, probable error of one determination† of wave-length of chief line= ± 0.05 tenth-meter.

For bright nebulæ, probable error of one determination of wave-length of chief line = ± 0.10 tenth-meter.

Combining these values with the probable error of the normal position of the chief line, the probable error of a displacement is:

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* *Proc. Roy. Soc.*, vol. 22, p. 251.

† Usually consisting of five measures.

	Tenth-Meters.	Miles.
For very bright nebulæ, one measurement,	$\varepsilon = \pm 0.058 =$	± 2.2.
For very bright nebulæ, two measurements,	$\varepsilon = \pm 0.046 =$	± 1.7.
For very bright nebulæ, four measurements,	$\varepsilon = \pm 0.039 =$	± 1.5.
For bright nebulæ, one measurement,	$\varepsilon = \pm 0.104 =$	± 3.9.
For bright nebulæ, two measurements,	$\varepsilon = \pm 0.077 =$	± 2.9.
For bright nebulæ, four measurements,	$\varepsilon = \pm 0.058 =$	± 2.2.

In some cases a larger probable error has been assigned to a measurement than that given by the above table, but in no case a smaller one.

MOTIONS OF NEBULÆ IN THE LINE OF SIGHT.

(A positive sign signifies recession; a negative sign, approach.)

Nebula.	λ	Displacement.	Motion in Line of Sight.
	Tenth-Meters.	Tenth-Meters.	Miles.
Orion	5007.34 ± .013	+ 0.29 ± .02	+ 11.0 ± 0.8
G. C. 826	5006.88	− 0.17	− 6.3
G. C. 2102	5007.15 ± .04	+ 0.10 ± .05	+ 3.7 ± 1.8
G. C. 4234 (Σ 5)	5006.48 ± .02	− 0.57 ± .03	− 21.3 ± 1.3
G. C. 5851	5006.19	− 0.86	− 32.0
G. C. 4373	5005.97 ± .04	− 1.08 ± .05	− 40.2 ± 1.8
G. C. 4390 (Σ 6)	5006.89 ± .01	− 0.16 ± .03	− 6.0 ± 1.2
N. G. C. 6790 . .	5007.86	+ 0.81	+ 30.1
G. C. 4510	5006.77	− 0.28	− 10.4 ± 2.8
G. C. 4514	5006.96 ± .02	− 0.09 ± .03	− 3.3 ± 1.5
N. G. C. 6891 . .	5007.73	+ 0.68	+ 25.3 ± 4.0
G. C. 4628	5006.22 ± .04	− 0.83 ± .05	− 30.9 ± 1.8
N. G. C. 7027 . .	5007.22 ± .01	+ 0.17 ± .03	+ 6.3 ± 1.2
G. C. 4964	5006.86	− 0.19	− 7.1 ± 3.0

There is a nearly constant difference of about ten miles between the motions given in the last column of this table and those published in my preliminary paper, due to the fact that the normal position of the chief line used in the preliminary reductions was not the result of comparison of known lines, but the mean of the positions of the chief line in the spectra of all the nebulæ then observed, as I have already explained. The *differences* of motion are almost exactly the same in both tables.*

It will be seen that approaching motions preponderate, as we should expect from the fact that most of the nebulæ are situated in that part of the heavens toward which the solar system is known to be moving.

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* With the exception of *G. C. 5851*. In the table of motions in the preliminary paper, the corrected wave-length of the chief line in the spectrum of this nebula was, by an error of transcription, given as 5005.50 (ÅNGSTRÖM).

These observations show that the nebulæ are moving in space with velocities comparable with those of the stars. As the physical association of stars and nebulæ shows that their distances are also of the same order, we should expect (from this point of view alone) to readily find evidence of proper motion of nebulæ. In fact, however, such evidence is almost wanting, the only probably well authenticated instance of change being the Trifid nebula in *Sagittarius*.* The difficulty of the observation is probably a sufficient explanation. In large, diffuse nebulæ there are no portions sufficiently definite for exact observations, and besides, stars involved in the nebula may be physically connected with it, and therefore useless as reference points. In the case of a planetary nebula we are *sure* that the star (or nucleus) in the center is in the nebula, and it gives us a sharply defined point for determining the position of the latter. Suitable reference points are also at hand. As a planetary nebula is small, stars can generally be found which, although so far from the nebula as to have almost certainly no physical connection with it, are yet within the field of a telescope at the same time with the nucleus, and therefore within the range of a micrometer. The nucleus and available comparison stars will usually be very small, and therefore a large telescope is required for the measurements. Micrometer observations of planetary nebulæ have recently been made by Mr. BURNHAM with the 36-inch refractor, and the data which he has obtained will be of great future interest in connection with the subject of the proper motions of the nebulæ.

X.

NORMAL POSITION OF THE SECOND NEBULAR LINE.

The comparisons of the second line in the spectra of a number of the nebulæ with the spectrum of iron give as many independent determinations of the normal position of the second nebular line. The apparent position, as determined by observation, is first corrected for the orbital motion of the earth, and then, by means of the known motion of the nebula in the line of sight, reduced to the normal position unaffected by any motion whatever. In the following table are given the results for such nebulæ as have been observed. They are all of nearly the same weight, as it happens that the fainter nebulæ have been more frequently observed. The wave-length (λ) corrected for orbital motion of the earth is affected by the probable error of measurement, which, for a single nebula, is about ± 0.07 tenth-meter, and the normal position (λ_0) is also affected by the probable error of the motion of the nebula in the line of sight (about ± 1.6 miles). Combining the probable errors according to the method of least squares, the resulting probable error of the normal position of the second line is very nearly ± 0.08 tenth-meter for each nebula. The probable error of the mean of the results for the five nebulæ in the table is therefore about ± 0.04 tenth-meter, a somewhat larger value than that obtained by comparing the individual results with the means.

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* HOLDEN. *Am. Jour. of Sc.*, vol. 14, p. 433.

NORMAL POSITION OF THE SECOND NEBULAR LINE, FROM COMPARISONS WITH THE IRON LINE AT λ 4956.79.

Nebula.	λ	Motion of Nebula.	Correction for Motion.	λ_0
	Tenth-Meters.	Miles.	Tenth-Meters.	Tenth-Meters.
Orion	4959.33	+ 11.0	− 0.29	4959.04
G. C. 2102	4959.06	+ 3.7	− 0.10	4958.96
G. C. 4373	4957.98	− 40.2	+ 1.07	4959.05
G. C. 4390	4958.90	− 6.0	+ 0.16	4959.06
N. G. C. 7027 . . .	4959.15	+ 6.3	− 0.17	4958.98
			Mean,	4959.02 ± 0.04

Besides the micrometer measures given in the above table, the measurements of the interval between the first and second lines by means of the graduated circle give the position of the second line. The final result is obtained by simply subtracting the measured interval from the normal place of the chief line on the wave-length scale. It should be observed that the interval between the first and second lines is theoretically not precisely the same in all cases, as both lines are not displaced equally by a motion of the nebula in the line of sight, but the interval is changed by only 0.01 tenth-meter by a velocity of 30 miles a second, and it is therefore practically constant. However, a correction has been applied in the only case in which it amounts to a unit in the last decimal place.

The results of the second class of measures are exhibited in the following table:

NORMAL POSITION OF THE SECOND NEBULAR LINE, FROM MEASUREMENTS OF THE INTERVAL BETWEEN THE FIRST AND SECOND LINES.

Nebula.	$\Delta\lambda$	λ_0
	Tenth-Meters.	Tenth-Meters.
Orion	48.13	4958.92
G. C. 4373 . .	47.91	4959.14
G. C. 4373 . .	48.04	4959.01
G. C. 4390 . .	47.89	4959.16
N. G. C. 7027 .	48.07	4958.98
N. G. C. 7027 .	47.82	4959.23
Means	47.98	4959.07

This result is in excellent agreement with that given by the micrometer measures; but employing the wave-lengths of the reference lines which were used in the preliminary reductions, there was a discrepancy of several tenths of a tenth-meter, and it was principally this fact which led me to conclude that the assumed wave-lengths were erroneous. Notwithstanding the inferior accuracy of the second method, as compared with the micrometer measures, the systematic difference of the results was so much greater than the error of observation that it was safe to ascribe it to errors in the assumed positions of the reference lines. The accurate values of the latter, supplied by Professor ROWLAND, reduce the discrepancy to only 0.05 tenth-meter.

The result of the micrometer measures will be adopted as the normal position of the second nebular line, which is therefore $\lambda_0 = 4959.02 \pm 0.04$.

XI.

CHARACTER OF THE NEBULAR LINES.

The aspect of the chief nebular line in the spectrum of the *Orion* nebula has already been referred to. Both the first and the second line have been observed frequently in many nebulæ, with dispersions ranging from that of a single 30° prism to that of the fourth spectrum of the ROWLAND grating. The 12-inch telescope was employed on some occasions, with the small spectroscope and a single 60° prism.

The result of my more extended observations of the *Orion* nebula is entirely in agreement with the statement in my preliminary paper: "With all these different degrees of dispersion, and also with the other spectroscopes employed, the nebular lines appeared to be perfectly monochromatic images of the slit, widening when the slit was widened, and narrowing to excessively fine, sharp lines when it was closed up. The brightest line showed no tendency to assume the aspect of a 'remnant of a fluting' under any circumstances of observation."

In no nebula that I have examined are the spectral lines finer and sharper than in the nebula of *Orion*. In *G. C. 4390* and *G. C. 4234* they are sharp at the border of the nebula, but are somewhat broad and hazy at the nucleus, and this aspect of the lines is indeed the usual one in most of the planetary nebulæ. The broadening is symmetrical, and all the nebular lines are apparently affected in the same way. The usual appearance of the lines in the spectrum of a planetary nebula is therefore evidently consistent with the view that the nebulæ are condensing gaseous masses.

The planetary nebula *N. G. C. 7027*, which is in many respects one of the most interesting of its class, has a brilliant nucleus with some remarkable spectroscopic features. The chief line is the brightest I have seen—much brighter than that of the *Orion* nebula—and the second line is proportionally bright. These two lines seem to be absolutely monochromatic; they show no broadening at the nucleus, which gives but a faint continuous spectrum. We have here a case, therefore, in which great luminosity—and, presumably, temperature—are unaccompanied by evidence of increased pressure.

Dr. HUGGINS has suggested that the faint continuous spectrum of some nebulæ might, with sufficient light, be found to consist of closely adjacent bright lines. While it may be true that such is really the nature of the continuous spectrum, I must say that with the means at my disposal I could find no continuous spectrum which showed evidences of resolvability. The lines, bright and faint, and the continuous spectrum, seemed to be distinctly separated luminous phenomena.

The observations of the character of the nebular lines were made principally with reference to Mr. LOCKYER'S explanation of the origin of the chief line, and their bearing on this interesting subject will next be considered.

XII.

COMPARISONS OF THE CHIEF NEBULAR LINE WITH THE SPECTRUM OF MAGNESIUM.

While the observations which are described in this paper were in progress, the hypothetical magnesium origin of the chief nebular line was the subject of much discussion, and I was therefore able to conduct my examination of nebular spectra with special reference to various points brought out during the discussion on both sides of the question. The conclusion reached, as the result of my investigations in this direction, was that there is no evidence in the visible spectrum of the presence of magnesium in the nebulæ. The reasons for this conclusion are given below, and of course many of them are not new; but my own observations were made with powerful apparatus under exceptionally favorable conditions, and they may give independent and decisive answers to questions that have been asked before.

Experience, as well as probability, shows that it is unsafe to base important conclusions on the apparent coincidence of single lines. It would be easy to mention instances of this kind, in which apparent coincidence has broken down when subjected to more careful examination with powerful instruments. The case of the chief nebular line and the magnesium fluting is another example of accidental juxtaposition, for the observations which have been described show that the nebular line, in its normal position, is 0.42 tenth-meter more refrangible than the terminal line of the magnesium fluting. The interval between the lines, though small, is fourteen times greater than the probable error of observation, and it has been shown that the measurements are practically free from constant errors.

We may now regard the question from the independent standpoint of the character of the lines. The chief nebular line is single and narrow; the magnesium fluting has seven or more sharp maxima separated by intervals slightly increasing toward the violet end of the spectrum. The lowest maximum is the brightest, and the others follow in the order of their distance, though their brightness does not, according to Professor HALE,* decrease uniformly, there being a sudden drop at the fourth maximum.

Professor LOCKYER considers that all the maxima, except the first, with part of its attendant fringe, are invisible in the spectra of the nebulæ, on account of their faintness. A number of observations are on record, in which the chief nebular line is described as having a fringe, sometimes more perceptible on the side toward the violet end of the spectrum. Some observers have always seen the lines sharp and well defined.

It is evident, therefore, that the aspect of the chief nebular line, as seen with an instrument of low dispersion, is a poor criterion of its character. A fringe on one side of a bright line might be produced by spherical aberration of the lenses, imperfect adjustment, displacement of the line from the center of the field, or other causes, and the delicacy of the observation throws too much upon the judgment of the observer. It is not my purpose, however, to explain the observations of others. My own observations, made with accurately constructed and carefully adjusted apparatus, showed that with every degree of dispersive power the nebular lines were either perfectly sharp or (near the nucleus of a planetary nebula) symmetrically widened.

Professor LOCKYER considers that a low dispersion is more suitable for this branch of the inquiry than a high one. To me this seems doubtful. The fringe, in order to be seen at all with low dispersion, would have to be several tenth-meters wide, and in that case the other maxima of the fluting should be plainly visible.

The visibility of the other maxima of the fluting is in fact a vastly more reliable criterion than the existence of a fringe on the more refrangible side of the first line. The magnesium fluting, in order to take on this latter aspect, must be reduced to the last degree of faintness, the exact intensity required being so critical that I have never succeeded in producing it experimentally. The first three maxima of the magnesium fluting are so nearly of the same brightness that it is next to impossible to obtain the first without the others.* The first nebular line in many cases has an intensity greatly exceeding this critical value.

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* *Sidereal Messenger*, January, 1891.

In this connection I would again call attention to the fact that the nebular spectra with the grating which I used were by no means extremely feeble; their brightness was often surprising to me. The second line in the spectrum of the ring nebula in *Lyra* was always easily seen with the grating, in the fourth spectrum as well as the third, and yet this line has frequently escaped observers using prisms and low dispersion.

As an example of many observations of the same kind, I will describe some comparisons of the spectrum of magnesium with that of the nebula *N. G. C. 7027*, which were made after the usual micrometer measurements had been completed. The chief nebular line was brilliant and very sharp. The first three maxima of the magnesium fluting were in the field, and formed as strong a contrast with the nebular line as one could well imagine. Even when dimmed far below the brightness of the nebular line all three maxima were seen, and their fluted character was apparent.

The magnesium spectrum was then thrown out of the field, and the slit was opened until the chief nebular line appeared as a monochromatic image of the nebula. An image one-tenth as bright could have been seen, and yet the places corresponding to the two other maxima of the magnesium fluting, which should, on the hypothesis of the magnesium origin of the nebular line, have been occupied by images almost as bright as the principal one, were perfectly blank. It would, I think, be difficult to conceive of a more conclusive test than this. The experiment was repeated in the third spectrum, and with the low power eye-piece, with the same result. The nebular spectrum at the place of the *b* group was also examined, but no lines were visible.

Other nebular spectra were examined at different times, in the same way and with the same results. It does not seem necessary to give a detailed account of the observations.

XIII.

THE ORIGIN OF THE NEBULAR LINES, AND THE CONSTITUTION OF THE NEBULÆ.

It has been shown, from a consideration of the observations made at the Lick Observatory (and I have purposely confined myself to them for the proofs), that the chief nebular line is not due to magnesium. We must therefore look elsewhere for the origin of the line, and in this connection I regret to say that my observations are, as was to be expected, entirely negative. There is no known terrestrial substance which has a strong line in the spectrum at the place of either the first or the second nebular line. For the first time the positions of the two brightest nebular lines have been determined with sufficient accuracy to enable us to say definitely whether they are or are not represented in the solar spectrum by absorption lines. Measuring off, on Professor ROWLAND'S new photographic map, a distance of 1.39 tenth-meters toward the red, from the center of the double iron line, which, on ROWLAND'S map, falls at λ 4957.6, we find that there is no line within over ⅓ tenth-meter of the place so determined, and hence no line which can be identified with the second line in the spectra of the nebulæ. In the same way we find by laying off a distance of 1.42 tenth-meters toward the red, from the place of the lead line at λ 5005.63, that there is no solar line on the map that can be identified with the chief nebular line. This does not, of course, prove that the substances giving rise to the nebular lines do not exist in the Sun, but only that such substances, if they exist, do not manifest themselves in the solar spectrum. The positions of the nebular lines in the solar spectrum are shown in the plate at the end of this paper.

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* See also Professor HALE's article in the *Sidereal Messenger*, January, 1891.

In all the nebulæ observed, the first and second lines had, as nearly as I could judge, a constant ratio of brightness, while that of either of them to the third line varied for different nebulæ. I am aware that a number of skilled observers have arrived at a different conclusion, and a comparison of their results even indicates variability in the brightness of the lines; but it *may* be that these apparent changes are sufficiently accounted for by errors arising from the difficulty of the estimations. If the first and second nebular lines do have a constant ratio of brightness in all nebulæ, there is some slight probability that they are due to the same substance, for although identity of origin does not exclude differences in the relative brightness of the lines, the variations of brightness would probably in this case be small.

I have made no observations bearing on the chemical significance of the fainter nebular lines.

A curious circumstance, for which I can find no adequate explanation, is the invisibility of the H_α line in the spectra of the nebulæ. In only one nebula (*G. C. 4390*) has this line been seen, and then only with difficulty, in the spectrum of the nucleus. The faintness of the light might easily account for this fact if the H_γ line were also invisible, but in laboratory experiments the H_α line of hydrogen is always, so far as I know, brighter than the third hydrogen line, or H_γ. A simple experiment which I made during the course of my observations showed plainly the difference between the spectrum of hydrogen in the nebulæ and that of an ordinary hydrogen tube. A piece of white paper was placed obliquely in front of the slit of a small direct-vision spectroscope, and the light from the electrically excited spectrum tube was allowed to fall upon it. At a distance of 12 or 15 feet the $H\beta$ line only was visible. On approaching the tube, the $H\alpha$ line was next seen, and finally the $H\gamma$ line. With the most powerful discharge that I could use with the tube the order of brightness of the lines was the same. With more powerful apparatus it is possible the relation of brightness of these lines may be reversed; if so, the fact would point to an extremely high temperature or high degree of electrical excitement of the hydrogen in the nebulæ.

I may point out that in some of the variable stars we appear to have hydrogen in the same condition as in the nebulæ. In the spectrum of R *Andromedæ*, near its maximum, I have seen $H\beta$, and several lines of the hydrogen series above it, glowing brilliantly, while not a trace of $H\alpha$ could be found. Miss CLERKE has suggested that the $H\alpha$ line may be blotted out by the absorption of some overlying metallic vapor, as the H_ϵ line in *o Ceti* is blotted out by the absorption of calcium, but this explanation, while it may be regarded as a plausible one in the case of a star, appears to be untenable when applied to the nebulæ.

The hydrogen lines in the spectra of *γ Cassiopeiæ*, *β Lyræ*, *Pleione*, and some others, all stars of VOGEL'S class I *c*, always seem to me, on the other hand, to follow the same order of brightness as the lines in the spectrum of a hydrogen tube. It is possible that the above-mentioned peculiarity in the spectrum of hydrogen, as found in the variable stars and the nebulæ, may some day considerably extend our knowledge of the physical conditions of these interesting bodies.

On the whole, the spectrum of the nebulæ is certainly indicative of a high temperature, however difficult it may be for us to furnish an explanation of the fact. The temperature may be high only in the restricted sense that comparatively few molecules have extraordinary velocities, and that the light of the nebulæ is produced by violent encounters among them, while the average molecular velocity, and hence the mean temperature of the gaseous body, is low.* Such a condition of things is known to us only in the case of gases electrically excited.

The presence of the D_3 line seen in the spectra of a number of planetary nebulæ is also apparently indicative of a high temperature. Professor LOCKYER considers a high temperature of the nebulæ so improbable that he attributes the presence of the D_3 line to "an action in space, away from condensations, whereby matter is reduced to its finest forms."† He regards the D_3 line as representing a fine form of hydrogen, and suggests that "the degree of fineness which is brought about by temperature in the case of the Sun, is brought about in the spaces between meteorites by extreme tenuity."*

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* HUGGINS, *Address as President of the British Association*, p. 21.

† *The Meteoritic Hypothesis*, p. 293. Professor LOCKYER subsequently modified his views, and now regards the D_3 line as due to the comparatively small number of end-on collisions among the meteorites of the swarm. *Phil. Trans.*, vol. 184, p. 714. (Note added May 1, 1894.)

While fully recognizing the difficulty of accounting for an exceedingly high temperature of the nebulæ, I think we must admit that all spectroscopic evidence tends to establish its reality, at least in the restricted sense already mentioned. The suggestion of Professor LOCKYER fails to explain the observed appearance of the D_3 line in the spectrum of a nebula like *G. C. 4390*. The D_3 line is barely visible in the diffuse part of the nebula, and is brighter and broader near the nucleus, as it should be on the supposition that it is there brought out by increased temperature, and as it should not be on Professor LOCKYER'S hypothesis.

I should state, however, that it is not absolutely certain that the yellow line in this and other planetary nebulæ is actually D_3. The observations with the small spectroscope showed that it was very nearly in the position of the latter, but were not sufficiently precise to establish the identity beyond question. Dr. COPELAND has shown that the D_3 line is present in the spectrum of the *Orion* nebula, and its existence in other nebulæ is therefore rendered more probable. The certain identification of the yellow line in the spectrum of *G. C. 4390* would make the lower part of the spectrum of this nebula much like that of *β Lyræ*, except that the presence of absorption lines is, in the case of the nebula, doubtful. On the other hand, it is possible that the yellow line may be the line at λ 5810 ± of the WOLF-RAYET stars, and the estimated positions of other faint lines in the lower part of the spectrum agree fairly well with VOGEL'S positions of bright lines in the spectra of DM. + 35° 4001 and DM. + 35° 4013.†

Professor LOCKYER seems to consider the identity of D_3 and the bright yellow line in *β Lyræ*, and other stars of its class, as still open to doubt, although measures by VOGEL and other observers appear to be decisive. Probably a measure of my own with the compound prism is the most accurate determination of the place of the yellow line in *β Lyræ* that has been made up to the present time, partly on account of the brilliancy of the spectrum with the 36-inch equatorial, and partly because the bright line was referred by micrometer measures to the dark D lines, which were visible in the same spectrum. The result showed conclusively that the bright line was D_3. The question is perhaps irrelevant in connection with the subject of the nebulæ, as, according to PICKERING, the stars of class I *c* are quite distinct from the bright-line stars of the WOLF-RAYET type, with which the planetary nebulæ are probably closely related,‡ although both classes of bright-line stars are placed by LOCKYER in a single sub-group.

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* *Proc. Roy. Soc.*, vol. 43, p. 139.

† Recent measurements by Professor CAMPBELL show that there is no doubt that the bright line in the yellow is D_3. (Note added May 1, 1894.)

‡ See, however, a paper by Professor CAMPBELL, on THE WOLF-RAYET STARS, *Astronomy and Astro-Physics*, June, 1894.

In my preliminary paper I pointed out the great resemblance between the spectra of the nuclei of planetary nebulæ and the spectra of stars of the WOLF-RAYET class. At the time I had not noticed that Professor PICKERING had called attention to the same fact in the then recently published fourth report of the *Henry Draper Memorial.* It is interesting to note that the similarity is apparent in both the visual and the photographic spectra. Professor PICKERING has since classified both objects together as forming a fifth type of stellar spectrum.*

During the summer of 1889, while studying the spectra of the bright line stars in *Cygnus*, I examined the stars of this type very carefully with the 36-inch equatorial. Mr. BURNHAM and Mr. BARNARD also examined the stars for traces of surrounding nebulosity, but with only negative results. If these objects have really been developed from planetary nebulæ, the nebulosity has either been completely absorbed into the nucleus, or what remains is too faint to impress the eye when aided with the most powerful telescope.†

XIV.

SUMMARY OF RESULTS.

The principal conclusions which have been reached as a result of these investigations are summarized below. Some of them are but a confirmation, by powerful apparatus and exact measurements, of results which had been rendered extremely probable by the labors of other observers. It is on account of the increased weight which is given to these results that they are included in the summary.

1. The normal position of the chief nebular line, or position which the line would have in the spectrum of a nebula at rest relatively to the observer, is $\lambda\,5007.05 \pm 0.03$ on ROWLAND'S scale.

2. The normal position of the second nebular line on ROWLAND'S scale is $\lambda\,4959.02 \pm 0.04$. This line is 1.39 ± 0.04 tenth-meters less refrangible than the center of the double line of iron at $\lambda\,4957.63$.

3. The first and second nebular lines are not represented by absorption lines in the solar spectrum, at least not by any lines sufficiently strong to appear in ROWLAND'S photographic map.

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* *Ast. Nach.,* 3025.

† Mr. ROBERTS has recently attempted to find evidences of nebulosity by long-exposure photographs, with the same negative results. It would seem as if this method should be inferior to eye observation, unless the nebulous atmosphere around the star is very extensive.

Note added May 1, 1894. Professor CAMPBELL has since shown (*Astronomy and Astro-Physics*, December, 1893) that the WOLF-RAYET star DM. + 30° 3639, which was not among the stars examined by Messrs. BURNHAM and BARNARD, is surrounded by an extensive hydrogen atmosphere.

4. The relative brightness of these two lines is, within the limits of error of estimation, the same for all nebulæ. Hence, there is some reason for thinking that they are due to the same unknown substance, perhaps an element of somewhat the same nature as the so-called helium.

5. The spectrum of the bright-line nebulæ indicates either a high temperature of the gases emitting the light, or a state of strong electrical excitement, and shows that the temperature and pressure are greatly increased at the nucleus.

6. The distance between the Great Nebula of *Orion* and the Sun is increasing at the rate of 11.0 ± 0.8 miles per second. This result shows that the nebula has little or no motion relatively to the center of figure of the stars from whose proper motions the drift of the solar system has been determined.

7. No relative motion of different parts of the *Orion* nebula could be detected; the limit of accuracy of the method, for the brighter parts of the nebula, being something like 4 or 5 miles per second.

8. The nebulæ are moving in space with velocities of the same order as those of the stars. A table, showing the measured velocities of particular nebulæ in the line of sight, is given elsewhere. Of the nebulæ observed, that having the greatest motion of approach, 40.2 miles per second, is *G. C. 4373;* that having the greatest motion of recession, 30.1 miles per second, is *N. G. C. 6790.* Most of the nebulæ have considerably smaller velocities than these.

9. The only direct attempt to detect rotation of a planetary nebula gave the negative result that there was no differential motion of opposite limbs amounting to as much as 7 or 8 miles a second.

10. The visible spectrum of the nucleus of a planetary nebula has in many cases a strong resemblance to that of stars of the WOLF-RAYET class, although the two principal nebular lines are absent from the latter; and still other differences exist, the importance of which cannot at present be exactly estimated.

The observations which have been described in this paper were intended to form part of a more extended research, which was brought to an end (so far as my own part in it was concerned) by my removal from Mount Hamilton to Allegheny. I have to express my obligations to Professor HOLDEN for every encouragement in the work, and for every facility in its prosecution which the equipment of the Observatory could furnish. I have also to thank Mr. W. W. CAMPBELL, then of the University of Michigan, and now of the Lick Observatory, and Mr. A. O. LEUSCHNER, of the University of California, for their efficient aid in the observations during the summer of 1890.

NOTE.—Since the above paper was written, less than four years ago, great advances have been made in the study of nebular spectra, chiefly by the application of photographic methods. The sections of my paper relating to instrumental errors might now be omitted, and the accuracy of the adjustments taken for granted; but it will be remembered that these observations were made before the spectroscope had really come to be regarded as an instrument of precision. Errors of several tenth-meters were common in visual observations, and the possibility of reaching a higher grade of accuracy was disputed; the positions of lines in the spectra of the common metals were very defective; the tables of ROWLAND and of KAYSER and RUNGE had not appeared, and only preliminary accounts of the photographic observations at Potsdam had been published. Hence, I have preferred not to incorporate in my paper the results of recent investigations, but to let it stand as representative of the time at which it was written. Most of the recent work does not indeed come within its province, but has advanced along other lines; no greater accuracy has been reached in measurement of the lines in the visual spectrum, or in determining the motions of the nebulæ in the line of sight. So far as I am aware, no attempts have been made to improve on these results. The greatest advance has been in the discovery of new lines in nebular spectra by photography, and in tracing the spectral relations between nebulæ and associated stars. It has been shown independently by Professor CAMPBELL and myself that nearly every line in the spectrum of the *Orion* nebula, with the important exception of the two principal lines in the visual spectrum, is represented by a prominent absorption line in the spectra of the brighter stars in the same constellation. The D_3 line of the nebula is represented by an absorption line in the spectrum of *Rigel*. It has also been shown that the spectra of the stars in the *Trapezium* are characterized by strong absorption bands, and do not, as formerly supposed, contain bright lines which blend with the lines of the nebula. Hence, these stars have not the intimate physical connection with the nebula that was until lately ascribed to them; they stand, in this connection, on the same footing as the other *Orion* stars, and within certain limits they may be placed anywhere on the line joining the nebula with the earth.

The principal papers bearing on nebular spectra which have appeared since my paper was written, and which are therefore not referred to in the text, are as follows:

—— Recent Observations of *Nova Aurigæ*. W. W. CAMPBELL. *Astronomy and Astro-Physics*, October, 1892.

—— The Spectrum of *Nova Aurigæ*. W. W. CAMPBELL. *Publications Astronomical Society of the Pacific*, November, 1892.

—— Studies on the Photographic Spectrum of the Planetary Nebulæ and of the New Star. EUGEN V. GOTHARD. *Astronomy and Astro-Physics*, January, 1893.

—— Concerning the Nature of *Nova Aurigæ's* Spectrum. W. W. CAMPBELL. *Astronomy and Astro-Physics*, October, 1893.

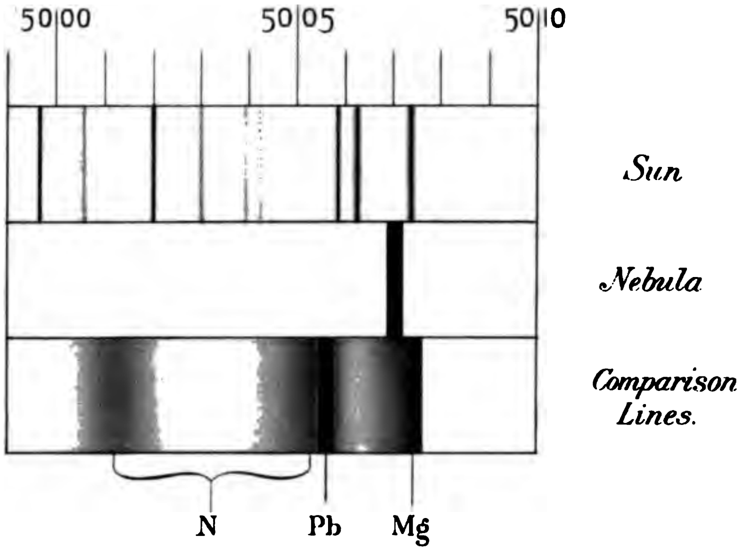
—— On the Photographic Spectra of Some of the Brighter Stars. J. N. LOCKYER. *Phil. Trans.*, vol. 184, p. 675.

—— Spectra of the Great Nebula of *Orion* and other well-known Nebulæ. W. W. CAMPBELL. *Astronomy and Astro-Physics*, May, 1894.

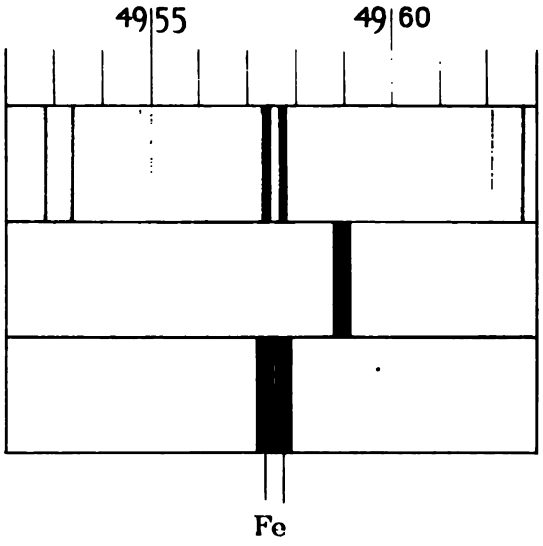
—— On the Spectra of the *Orion* Nebula and the *Orion* Stars. JAMES E. KEELER. *Astronomy and Astro-Physics*, June, 1894.

—— The WOLF-RAYET Stars. W. W. CAMPBELL. *Astronomy and Astro-Physics*, June, 1894.

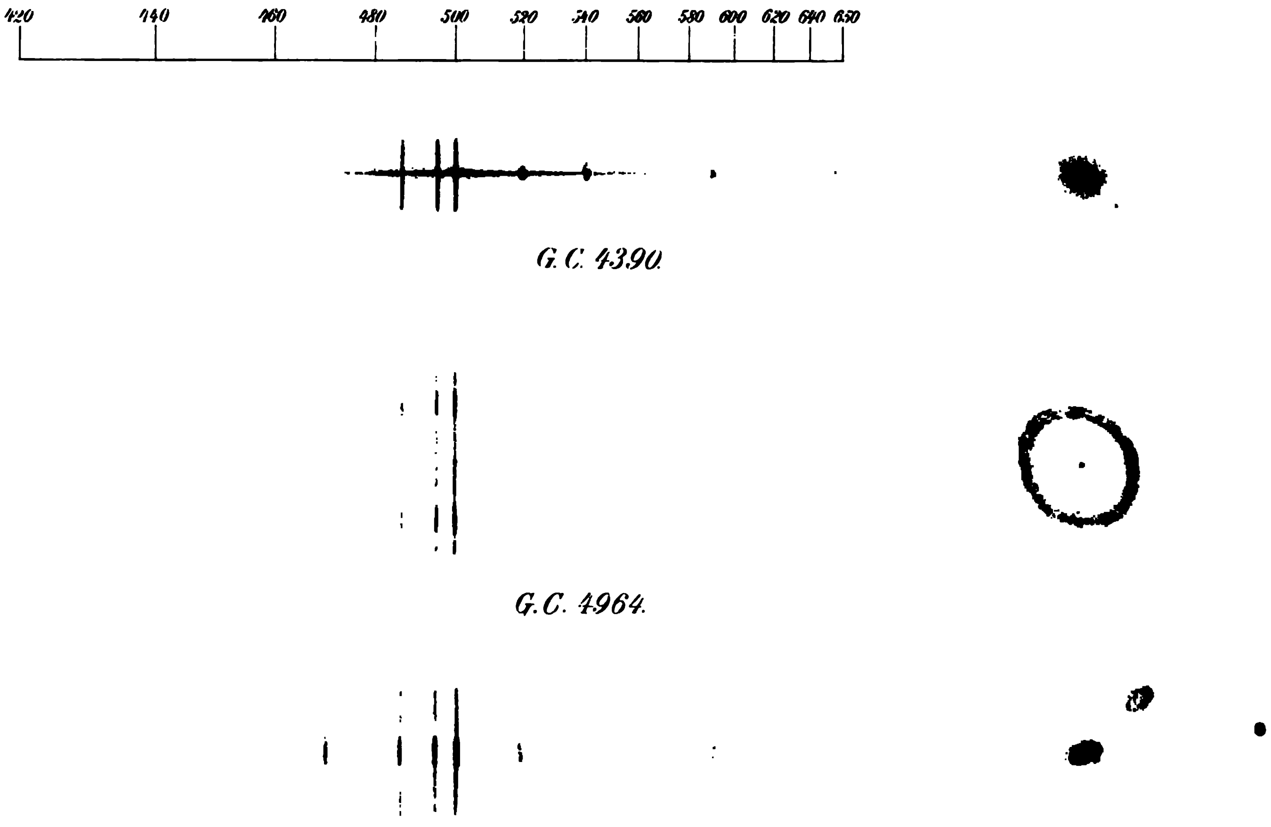
Allegheny Observatory, June 1, 1894.



Normal Position of the Chief Nebular Line.



Normal Position of the Second Nebular Line.



G. C. 4390.

G. C. 4964.

N. G. C. 7027.

Visible Spectra of Planetary Nebulae

J. E. Keeler.

WORKS ISSUED BY THE LICK OBSERVATORY.

⁂ It is intended to issue, at irregular intervals, two series of works: the first, in quarto, to be known as *Publications* of the Lick Observatory; the second, in octavo, to be known as *Contributions* from the Lick Observatory. Occasional pamphlets, such as No. 2 below, may not be included in either series. At the end of every book, a list of all the works issued will be given, for the convenience of librarians and others.

For the sake of uniformity, Nos. 3 and 4 below will be counted as *Contributions* Nos. 1 and 2.

1. *Publications* of the Lick Observatory of the University of California, prepared under the direction of the Lick Trustees by EDWARD S. HOLDEN, Volume I, 1887. Sacramento, 1887. 4to. [Containing a brief history of the Observatory, with descriptions of the buildings and instruments; observations of double stars by S. W. BURNHAM, 1879; of the transit of *Mercury*, 1881, by Messrs. FLOYD, HOLDEN, and BURNHAM; of the transit of *Venus*, 1882, by D. P. TODD; meteorological observations, by T. E. FRASER, 1880–85; and Reduction Tables for Mount Hamilton, by G. C. COMSTOCK.]

2. Suggestions for Observing the Total Eclipse of the Sun on January 1, 1889, by EDWARD S. HOLDEN. Printed by authority of the Regents of the University of California. Sacramento, 1888. 8vo. [Out of print.]

3. *Contributions* from the Lick Observatory, No. 1. Reports on the Observations of the Total Eclipse of the Sun of January 1, 1889, published by the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1889. 8vo. [Out of print.]

4. *Contributions* from the Lick Observatory, No. 2. Reports on the Observations of the Total Eclipse of the Sun, December 21–22, 1889, and of the Total Eclipse of the Moon, July 22, 1888, to which is added a Catalogue of the Library, published by the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1891. 8vo. [Out of print.]

5. *Contributions* from the Lick Observatory, No. 3. Terrestrial Atmospheric Absorption of the Photographic Rays of Light, by J. M. SCHAEBERLE, Astronomer in the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1893. 8vo.

6. *Publications* of the Lick Observatory of the University of California. Printed by authority of the Regents of the University. Volume II, 1894. Sacramento, 1894. 4to. [Containing double star observations made with the 36-inch and 12-inch refractors of the Lick Observatory from August, 1888, to June, 1892, by S. W. BURNHAM.]

7. *Publications* of the Lick Observatory of the University of California. Printed by authority of the Regents of the University. Volume III, 1894. Sacramento, 1894. 4to. [Containing drawings and photographs of the Moon by Prof. LADISLAS WEINEK, reproduced in heliogravure, etc., from negatives made at the Lick Observatory, with an introduction by EDWARD S. HOLDEN; investigation of prisms of optical glass, by Prof. C. S. HASTINGS; investigation of the glass scale of the Lick Observatory Measuring Engine, by Mr. O. H. TITTMAN; spectroscopic observations of nebulæ, by Prof. J. E. KEELER.

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